Research Report
KTC-93-5

EVALUATION OF CLSM (FLOWABLE FILL) FOR TRENCH BACKFILL

by

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METRIC CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO METRIC UNITS					APPROXIMATE CONVERSIONS FROM METRIC UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH					**LENGTH**		
in.	inches	25.40000	millimetres	mm	mm	millimetres	0.03937	inches	in.
ft	feet	0.30480	metres	m	m	metres	3.28084	feet	ft
yd	yards	0.91440	metres	m	m	metres	1.09361	yards	yd
mi	miles	1.60934	kilometres	km	km	kilometres	0.62137	miles	mi
		AREA					**AREA**		
in.^{2}	square inches	645.16000	millimetres squared	mm^2	mm^2	millimetres squared	0.00155	square inches	in.^{2}
ft^2	square feet	0.09290	metres squared	m^2	m^2	metres squared	10.76392	square feet	ft^2
yd^2	square yards	0.83613	metres squared	m^2	m^2	metres squared	1.19599	square yards	yd^2
ac	acres	0.40469	hectares	ha	ha	hectares	2.47103	acres	ac
mi^2	square miles	2.58999	kilometres squared	km^2	km^2	kilometres squared	0.38610	square miles	mi^2
		VOLUME					**VOLUME**		
fl oz	fluid ounces	29.57353	millilitres	ml	ml	millilitres	0.03381	fluid ounces	fl oz
gal.	gallons	3.78541	litres	l	l	litres	0.26417	gallons	gal.
ft^3	cubic feet	0.02832	metres cubed	m^3	m^3	metres cubed	35.31448	cubic feet	ft^3
yd^3	cubic yards	0.76455	metres cubed	m^3	m^3	metres cubed	1.30795	cubic yards	yd^3
		MASS					**MASS**		
oz	ounces	28.34952	grams	g	g	grams	0.03527	ounces	oz
lb	pounds	0.45359	kilograms	kg	kg	kilograms	2.20462	pounds	lb
T	short tons (2000 lb)	0.90718	megagrams	Mg	Mg	megagrams	1.10231	short tons (2000 lb)	T
		FORCE AND PRESSURE					**FORCE**		
lbf	pound-force	4.44822	newtons	N	N	newtons	0.22481	pound-force	lbf
psi	pound-force per square inch	6.89476	kilopascal	kPa	kPa	kilopascal	0.14504	pound-force per square inch	psi
		ILLUMINATION					**ILLUMINATION**		
fc	foot-candles	10.76426	lux	lx	lx	lux	0.09290	foot-candles	fc
fl	foot-Lamberts	3.42583	candela/m^2	cd/m^2	cd/m^2	candela/m^2	0.29190	foot-Lamberts	fl
		TEMPERATURE (exact)					**TEMPERATURE (exact)**		
°F	Fahrenheit temperature	5(F-32)/9	Celsius temperature	°C	°C	Celsius temperature	1.8C + 32	Fahrenheit temperature	°F

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EXECUTIVE SUMMARY

Controlled Low Strength Material (CLSM), commonly referred to as flowable fill, has been used for years as a trench backfill for utility repairs in Kentucky, but had not been previously used by the Kentucky Department of Highways (KDOH). In 1991, the KDOH awarded a contract for the reconstruction of Breckinridge Lane in Louisville where CLSM was used as trench backfill for all storm drainage. In 1992, the KDOH awarded a contract for replacement of cross drains for US 25 in Fayette County where CLSM was used as trench backfill. These two sites were monitored for field performance, cylinders were cast for laboratory testing, and a laboratory mix design study was conducted.

CLSM appears to be a very effective trench backfill when placed in a sufficiently flowable state. The two sites monitored included both concrete and steel pipe with the concrete pipe in a cradle bedding and the steel pipe completely encased in CLSM. There were few problems at either site after the CLSM mix had been adjusted to a flowable condition. The CLSM 28-day compressive strength, typically, ranged from 50 to 150 psi, with strengths as low as 36 psi and as high as 668 psi. In the interest of removability, CLSM strength should be low, probably less than 100 psi at 28 days.

A mathematical relationship developed by Brewer and Associates appears to reasonably evaluate the removability of CLSM when actual compressive strength is used. Since cylinders are not usually available for long term testing, a method for predicting ultimate compressive strength is included.

A cost comparison of CLSM and conventional backfill (manufactured limestone sand) indicates that when trench dimensions are the same and only direct costs (labor, materials, equipment, and associated costs) are included, CLSM costs approximately $9.50 per foot of pipe more than conventional backfill for a six-foot by six-foot trench. Other costs stemming from increased productivity, less inspection, less testing, reduced liability concerns, and reduced or no future remedial work associated with the use of flowable fill which were not quantified nor included in the cost comparison would tend to reduce the total cost difference between CLSM and conventional backfill. Because conventional backfill normally requires additional trench width for compaction equipment, a reduction of trench width on each side of a pipe from 21 inches down to 12 inches can be realized when using CLSM. The reduced trench width makes CLSM costs equivalent to conventional backfill, on a direct cost basis.

A mix design study involving the use of manufactured limestone sand (MLS) as compared to natural river sand for CLSM filler was conducted. Findings from this task indicate that CLSM with MLS filler is not suitable for typical highway construction due to increases in strength, bleed time, time required to develop acceptable bearing capacity, and shrinkage.

Both experimental sites are currently being monitored to assess long-term pavement settlement.

INTRODUCTION

Differential settlement between trench backfills and surrounding material has long been a problem at cross drains in new construction, cross drain replacement or repair for older facilities, and utility openings in existing facilities. Differential settlement is usually the result of insufficient compaction of trench backfill material. The condition is most often observed where utility repairs or new utility construction takes place in existing roadways. The result of the differential settlement is a shallow dip or trench often running long distances longitudinally to the roadway with occasional trenches extending perpendicular to the roadway centerline. The same condition is often observed where cross drains have been replaced and in some cases miles of newly constructed roadway have required remedial action due to this condition.

A search for a solution for this problem resulted in the development of a low-strength flowable backfill material in the early 1970's. The material was developed and patented by private industry under the trade name K-Krete (CDF - Controlled Density Fill). The practicality of the low-strength backfill was soon apparent and several similar materials were developed. Due to the number of materials and inconsistency or scarcity of information available to the public, the American Concrete Institute (ACI) Committee 229 was formed to address issues relating to this type material. The ACI committee designated the material as Controlled Low Strength Material (CLSM) and defined low strength as less than 1,200 psi compressive strength at 28 days.

CLSM has a variety of uses including removable backfills, structural fills, insulating and isolating fills, void fills, bridge and culvert restoration, foundation improvement and many others. For use as a removable trench backfill, as in this study, a cubic yard of CLSM typically consists of:

. 40 to 100 pounds of Type 1 Portland cement,
. Approximately 300 pounds of Fly Ash (Type F),
. 2,500 to 2,800 pounds of fine aggregate (concrete sand), and
. 500 to 600 pounds of water.

This mix usually produces a flowable, self-leveling backfill having a 28-day compressive strength from 50 to 150 psi.

In 1991, the Kentucky Department of Highways (KDOH) decided to use CLSM as a trench backfill. The initial application was as a backfill for all storm drain trenching in the reconstruction of Breckinridge Lane in Louisville (project SSP 056 1932 001-003). After this evaluation was initiated, Division of Maintenance personnel specified CLSM as the trench backfill for a cross drain replacement project (MP 034 0025 003-008) on US 25 in Fayette County. This project was added to the study.

Due to the experimental nature of CLSM, the KDOH contracted with the Kentucky Transportation Center (KTC) to monitor and evaluate the use of CLSM as a trench backfill. The stated objectives of the study were:

A. To document construction procedures and evaluate CLSM as a backfill material,
B. to analyze the cost effectiveness of the use of CLSM, and
C. to make recommendations relative to future use of CLSM.

The work plan consisted of two primary parts with Part 1 being the documentation of construction procedures and evaluation of field performance. To be included were site and trench conditions, construction personnel required, placement techniques, workability and other characteristics of CLSM, quantities placed, and production comparing CLSM and conventional backfill. Part 2 primarily consisted of a laboratory evaluation of engineering characteristics including mix design, flowability, compressive strength, permeability, air content, density, yield, and shrinkage. Other factors considered were conduit stresses, pavement settlement, possible changes in trench dimensions, and variables encountered with use of CLSM and different conduit material (metal, concrete, and plastic).

One of the first efforts was to contact local utilities and municipalities to determine the extent of use and degree of satisfaction with CLSM. Two agencies which use CLSM extensively are the Louisville Gas and Electric (LG&E) and the city of Richmond, KY. Each agency has used CLSM for years and LG&E, has several thousand cubic yards placed in hundreds of trench backfills. Both agencies are pleased with CLSM performance and are of the opinion that when all factors (including call backs and safety considerations) are included, the use of CLSM is a cost-effective alternative. Sites were observed in Richmond where CLSM had been placed and paved over. Conditions were varied and included trench backfills that had been in place for two years, backfills that were paved over at reduced CLSM curing times (three to four hours), and trenches that were backfilled and paved during all seasons. There was no observable trench settlement and all pavement patches were in good condition.

SITE DESCRIPTIONS

<u>Breckinridge Lane, Louisville</u>

This project consists of the reconstruction, including grade change, and widening of approximately 7,154 feet of Breckinridge Lane. Breckinridge Lane is a rolling urban arterial with approximately 30,000 ADT. The project began at Station 43+01 near Hikes Lane and proceeded south along Breckinridge Lane to Station 114+55 near Landside Drive. Storm drain facilities consisted of reinforced concrete pipe ranging from 15 inches to 42 inches in diameter and included both circular and elliptical sections. Figure 1 includes a location map for this site.

Monitoring of CLSM placement and test cylinder casting was conducted throughout the project. Three cross drains were chosen for monitoring pipe stress and comparing CLSM backfill costs to conventional backfill costs. The cross drains chosen for instrumentation were: a 24-inch circular pipe at Station 94+44, an 18-inch equivalent (horizontal elliptical pipe) at Station 97+60, and a 30-inch circular pipe at Station 103+98. All pipe at this site were installed according to KDOH Standard Drawing for Pipe Bedding and Trench Condition.

Most of the pipe at this site ran parallel to centerline. This permitted long sections to be prepared and poured. Due to the fact that Breckinridge Lane was being widened from two to four lanes, traffic was maintained on two lanes while construction proceeded on the other two lanes. Approximately 3,125 cubic yards of CLSM were used to backfill approximately 7,081 feet of trench.

Richmond Road (US 25), Fayette County

This project consists of the replacement of ten old substandard cross drains on US 25 in southern Fayette County. The project began at mile point 3.548 (0.916 mile north of I-75 Overpass) and ended at Milepoint 7.470 (0.774 mile south of KY 418), a distance of 3.922 miles. The cross drains replaced were at the beginning and ending milepoints and at milepoints 3.679, 3.985, 4.156, 5.993, 6.142, 6.546, and 6.83. The pipes ranged in size from 30-inch equivalent (horizontal elliptical) to 42-inch circular. Culvert pipe alternates permitted were reinforced concrete, steel, and aluminum. The alternate installed was BCCSP 12 gage (steel) for circular pipe and BCCSP 14 gage (steel) for the 30 inch-equivalent pipe.

United States Route 25 at the site, is a two-lane rural road with narrow shoulders, steep side slopes, and ADT of approximately 3,000. The contractor was required to maintain one lane of traffic, except for momentary delays, and to have both lanes open when construction crews were not present. The cross drains ranged from 42 to 64 feet in length and from four to ten feet cover (from top of pipe to the surface). Figure 2 includes a location map for Site 2.

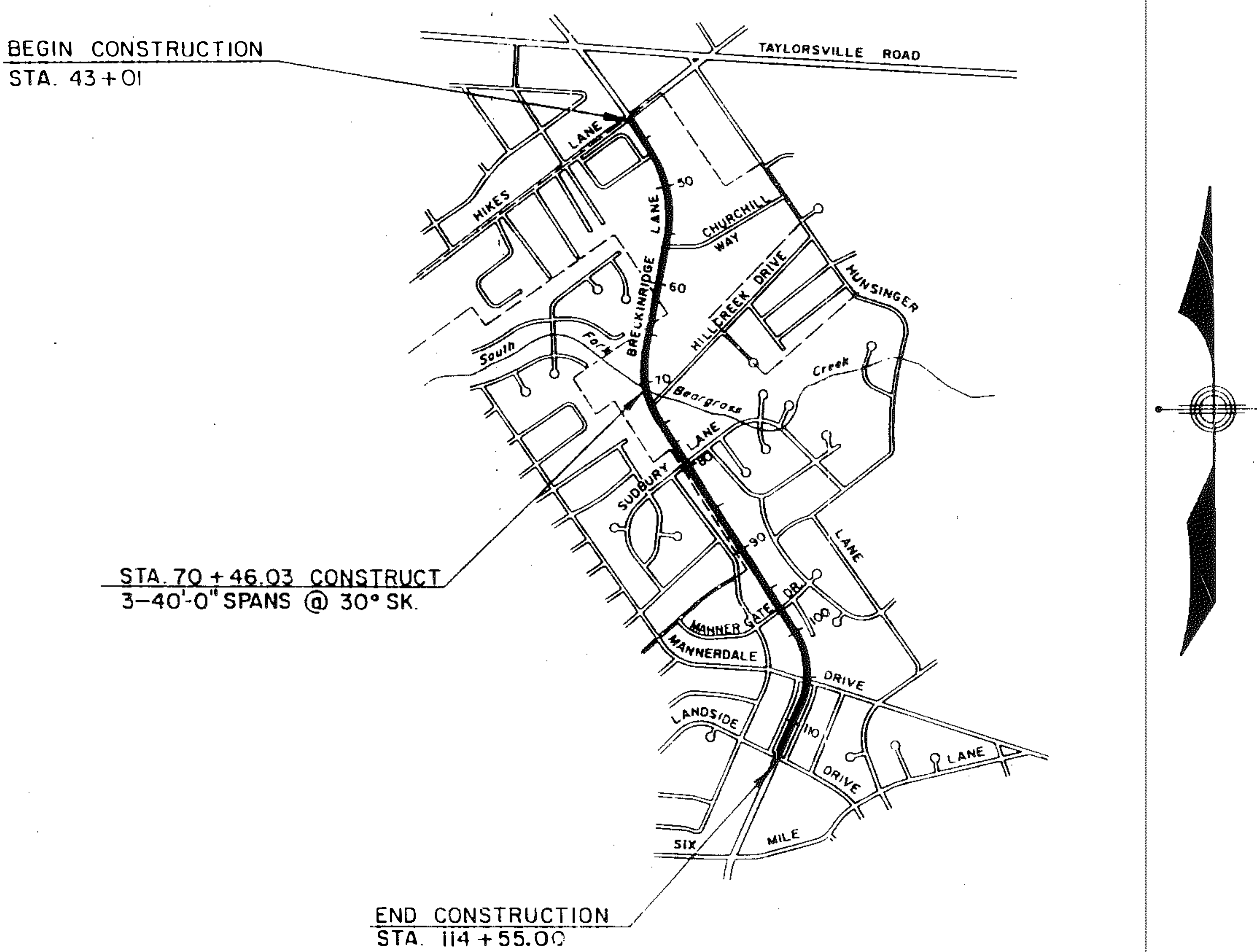

Figure 1. *Location of Site 1 at Breckenridge Lane in Louisville.*

FIELD EVALUATION

Breckinridge Lane, Louisville, (Site 1)

The general procedure was to open as much trench and place as much bedding and pipe as could be backfilled with CLSM by the end of the work day. In some cases, this was several hundred linear feet of pipe. The Cross drains were constructed to near the centerline and completed when traffic had been switched to the completed lanes.

There were few problems with the use of CLSM. The lack of experience led to some changes during the beginning of the project. The design mix of 50 pounds cement, 300 pounds fly ash, 2,750 pounds natural sand, and 500 pounds water was too dry to flow properly and the addition of 18 gallons (150 pounds) of water at the site produced a very thin or watery CLSM. The mix design was altered to include 583 pounds (instead of 500 pounds) of water at the concrete plant. This mix performed well throughout the remainder of the project.

Another problem was the lack of clearly defined acceptance criteria specified for CLSM for this project. The Special Note for Use of Flowable Fill as Pipe Backfill (Appendix A) noted that bleed water should appear on the surface within five to ten minutes and that test cylinders would be cast for each 100 cubic yards of CLSM. The cylinders were expected to have a compressive strength of approximately 50 psi at 28 days. The initiation of bleeding is a very subjective judgement but for this project was clearly within acceptance criteria. A potential problem exists with the determination of compressive strength and thus the removability of the CLSM backfill if repair or replacement should be necessary at a later date. By the time compressive strength of the CLSM was determined, hundreds of feet of pipe had already been installed.

The CLSM was consistently a flowable satisfactory backfill material. The CLSM flowed freely to fill any voids and began to bleed within two to three minutes of placement. Temporary forms made of plywood templates were placed over the pipe and staked in place where required. The forms were easily removed the next day and the CLSM was sufficiently cured to stand alone. An additional benefit to the contractor was the ability to form the CLSM very close to the location of precast boxes or drop inlets. When the precast structures were in place, the small volume surrounding them was filled. In the case of cast-in-place structures, the CLSM form work may be located so that, when the forms are removed, the CLSM may serve as part of the forming for cast-in-place structures.

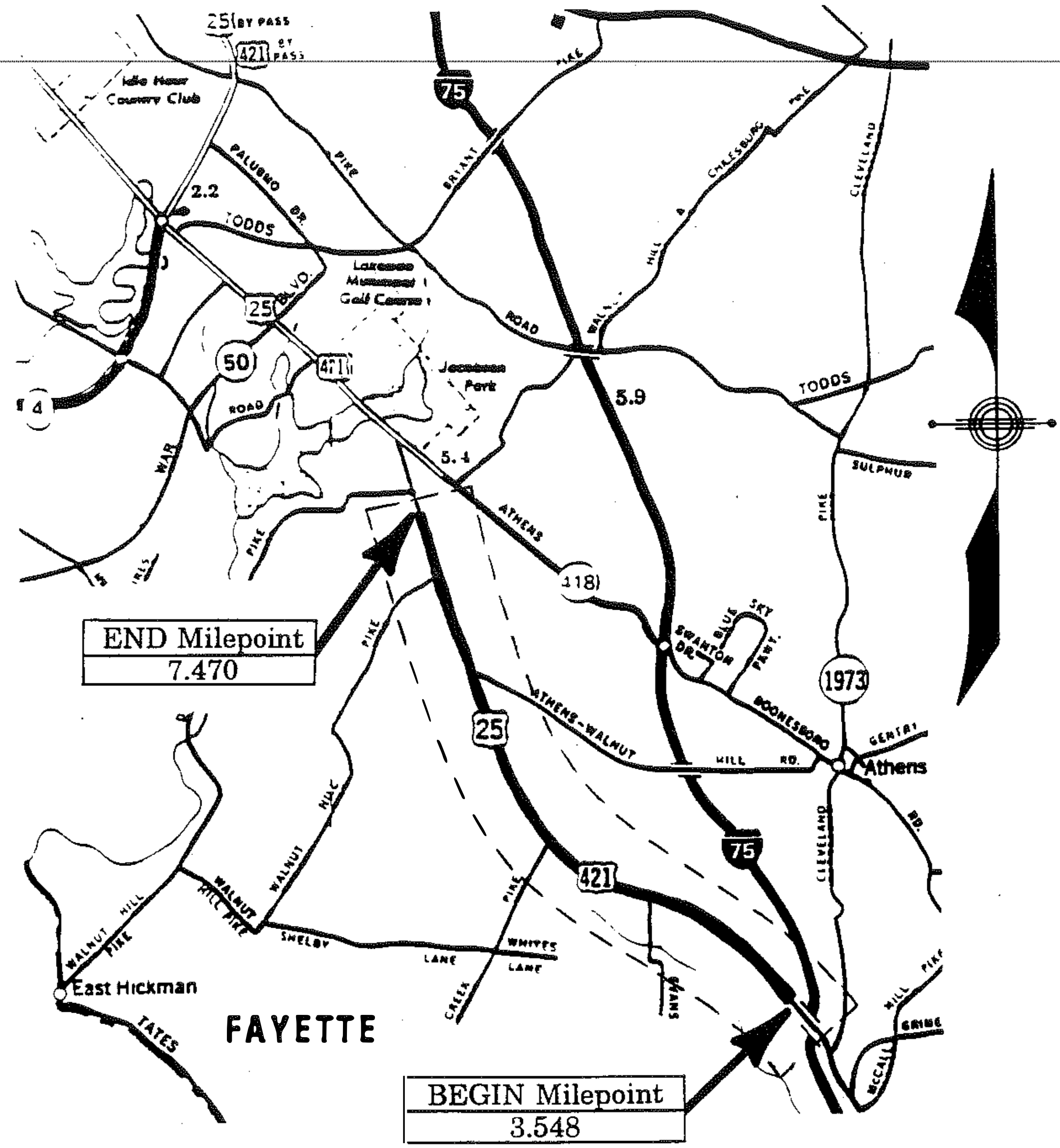

Figure 2. *Location of Site 2 at US 25 in Fayette County.*

The contractor had three to four workers available the first day CLSM was placed. Thereafter, only one laborer was needed to direct the CLSM into the trench. For this project, the Standard Drawing for Pipe Bedding and Trench Conditions was closely followed. Limestone sand (Class I sand) was placed for bedding, compacted, and a template was use to form a cradle conforming to pipe contours. The depth of the cradle was 0.3 Hc (where Hc is the outside diameter of the pipe). The cradle maintained pipe alignment and the weight of the reinforced concrete pipe prevented flotation. No recurring problems with CLSM placement were experienced.

Trenches were filled to the top or near the top with CLSM. After curing, surrounding soil was used to dress and smooth the area. In some cases where CLSM backfilled trenches crossed entrances, the CLSM was placed to within approximately six inches of the surface, allowed to cure approximately one hour, dense graded aggregate (DGA) was compacted in the trench to maintain grade, and traffic was allowed on the backfill in a little over one hour. A bituminous concrete patch was placed within two days. After more than a year of service, there is no evidence of backfill subsidence.

Richmond Road (US 25), Fayette County, (Site 2)

The general procedure was to remove the existing pipe to the centerline, place 9M gradation limestone aggregate for bedding, place the pipe with sandbagging at both ends for retention of the CLSM, then backfill with CLSM. The 9M aggregate was used primarily as a leveling and grading material with no attention given to compaction. The engineer overseeing this project determined that cradle bedding was not required. The entire pipe was encased in CLSM.

Sandbags at the centerline end of the pipe were stacked to the top of the excavation. Sandbags at the slope end of the pipe were stacked to the top of the pipe and then stepped back as depth of CLSM increased to approximate the existing slope. After the CLSM had cured sufficiently to stand alone, the procedure was repeated for the remaining portion of the cross drain. The ten cross drains were replaced in four days.

The proposed CLSM mix design was 40 pounds of Type I Portland cement, 300 pounds of Class F fly ash, 2,750 pounds of natural sand, and 500 pounds of water. An air-entraining agent was later added to increase the air content to ten percent. The ten percent air content was a target air content and was not confirmed by testing. The Special Note (Appendix B) for use of CLSM on this project did not include cylinders or bleed time criteria.

Unfamiliarity with the CLSM and lack of detail in the Special Note led to problems. The first four pours, the inlet ends to centerline of the four southern most cross drains, had drier than normal CLSM. The CLSM was so dry that it stacked instead of flowing (Figures 3 and 4). Bleed times were impossible to determine. In some cases, small quantities of bleed water were observed, but only after several (ten to 20) minutes.

Two obvious problems resulted from the use of dry CLSM. One was the inability of the CLSM to flow around the pipe. The photograph in Figure 5 was taken after the sandbags had been removed from the inlet end of a cross drain trench backfilled with dry, nonflowing CLSM. The voids underneath the pipe do not permit uniform support for the pipe.

Another problem was that the dryer CLSM did not have the bearing capacity of wetter, more flowable CLSM after three to four hours of curing. It appears that the addition of sufficient water to initiate the dynamic bleeding causes repositioning of solid particles and densification of the CLSM. The relatively high friction angle (39 degrees) of the aggregate/fly ash filler maintains the initial position of the particles (with greater voids) unless bleeding or some other influence, possibly vibration, causes densification. Densification of CLSM through bleeding is similar to the densification of sand backfill through jetting as used by many utility agencies. In this case, the volume and density of the CLSM remained relatively constant until traffic was permitted on the backfill. The vibration and cyclic loading caused by the traffic apparently induced partial liquefaction of the CLSM. Liquefaction results in particle repositioning, increased pore water pressure, and decreased bearing capacity of the CLSM.

After a trench had been backfilled to within six to eight inches of the surface, steel plates were placed to maintain traffic over the trench until the CLSM was sufficiently cured to support compaction of DGA to complete the backfill.

Instrumentation

The only instrumentation involved with this study was the placement of pressure meters on the pipe. Pressure exerted on the pipe was considered important due to possible future use of CLSM with other types of pipe, in particular plastic pipe, and to address the possibility of encasing the pipe in CLSM rather than using a bedding cradle. Pipe loading could be the result of weight of backfill, differential settlement, and especially in the case of shallow cover over the pipe, traffic induced loads. If there were significant settlement of the surrounding fill, the pipe could receive relatively high loads due to down drag on the rigid CLSM backfill.

Figure 3. *Illustrative of CLSM placed at Site 2. Material is dry enough to stack and should not be used as trench backfill.*

Figure 4. *Representative of CLSM used at Site 2. Water has been added to original mix. CLSM exhibiting cracks is not satisfactorily flowable.*

Figure 5. *Voids under pipe where dry CLSM was used as backfill.*

In order to receive shipment of the meters in time for the first installation, the meters were ordered before a thorough analysis of the instrumentation needs were completed. Six meters were obtained for installation at Site 1 and later, four were obtained for Site 2. A finite element analysis (1) indicated that the culverts placed in a cradle and backfilled with CLSM could have high loading at the interface of the bedding and CLSM.

At Site 1, two culverts had a meter installed on top and underneath each pipe. The meters were placed under the driving lanes. These pipes were at Stations 94+44, 24 inch, and 97+60, 18-inch equivalent. One 36-inch culvert at Station 112+37 received one meter underneath the pipe and one in the bedding immediately below the CLSM. The three instrumented pipes were backfilled with CLSM right of centerline and with conventional backfill left of centerline. Typical sections showing both instrumentation schemes are shown in Figures 6 and 7. Two meters were installed, top and bottom, on the conventional backfill end of the pipe at station 97+60.

Four meters were installed at Site 2. Two culverts were instrumented with a meter placed on top of each culvert and a meter placed underneath each culvert. For reasons

unknown, two of the meters, both on top of the pipe, did not function after the backfill was complete.

Flow Test

At the time this study was initiated, limited information was available on field testing for acceptance or describing CLSM. The industry recommended testing for flow, compressive strength, and observing bleed time. The recommended flow test apparatus was a smooth open ended cylinder three-inches in diameter and six-inches long. The cylinder was to be placed on a smooth, flat, level, non porus surface, filled with CLSM, and lifted vertically. The diameter of the resulting puddle of CLSM was expected to measure eight inches.

This procedure proved to be very difficult to use in the field. The original mix design at Site 1 included 500 pounds of water per cubic yard of CLSM. This mix, when subjected to the cylinder flow test, produced a puddle of four to five inches and was not flowable. The adjusted mix (including approximately 580 pounds of water) was satisfactorily flowable but flow test results were not repeatable. The heavier particles in the CLSM settled out before the cylinder could be filled, the plate cleared, and the cylinder lifted. The cylinder flow test was discontinued after several days use with consistently scattered test results. Subsequent experience with laboratory testing indicates that field flow testing might be feasible through use of a different test technique.

Cylinders

The Special Note for Use of Flowable Fill for Site 1 required that KDOH personnel cast a set of cylinders for each 100 yards of CLSM. The test cylinders were to bleed for 30 minutes, be refilled, covered with plastic or cylinder caps, and covered with wet burlap. The burlap was removed after 24 hours and the cylinders cured in the mold for 28 days. KDOH personnel adhered to the Special Note procedure and used six-inches diameter by 12-inches high molds.

KTC personnel cast four-inches diameter by eight-inches high cylinders. Paper, waxed paper, and plastic molds were used with the waxed paper and plastic molds being abandoned in favor of the unwaxed paper molds. The opinion of research personnel was that unwaxed paper more closely approximated the permeability of the in-situ confining medium. Based on the experience gained from the first few castings, the general casting and curing procedure was to fill the molds, cap or seal the top, leave undisturbed in the field for four to five days and then transport to the laboratory in a padded container. In the laboratory, remove the seal and bottom of the mold, and store in the open ended

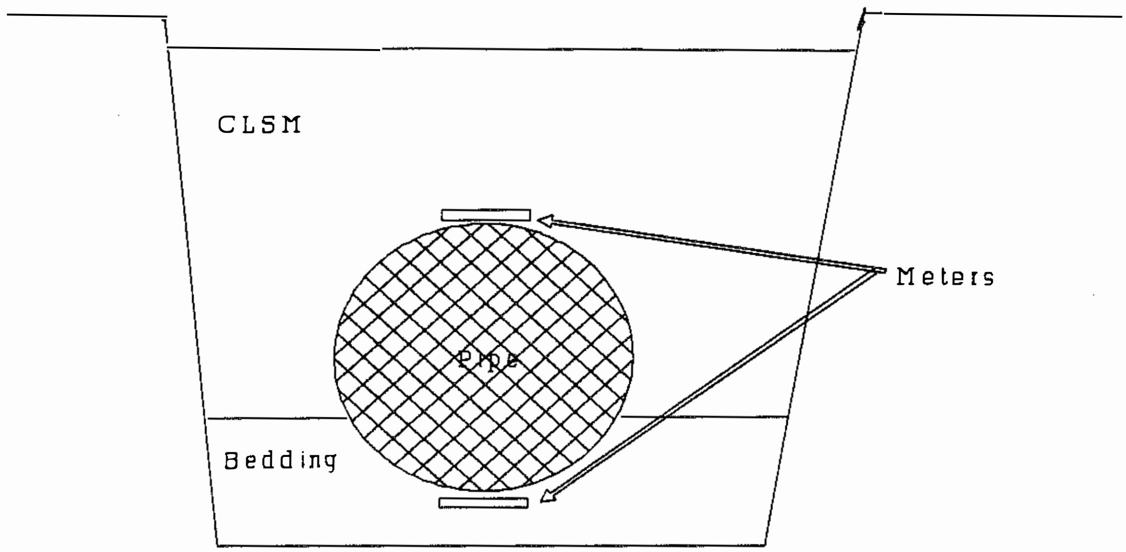

Figure 6. *Pressure meter location on all instrumented pipes except the 36-inch pipe.*

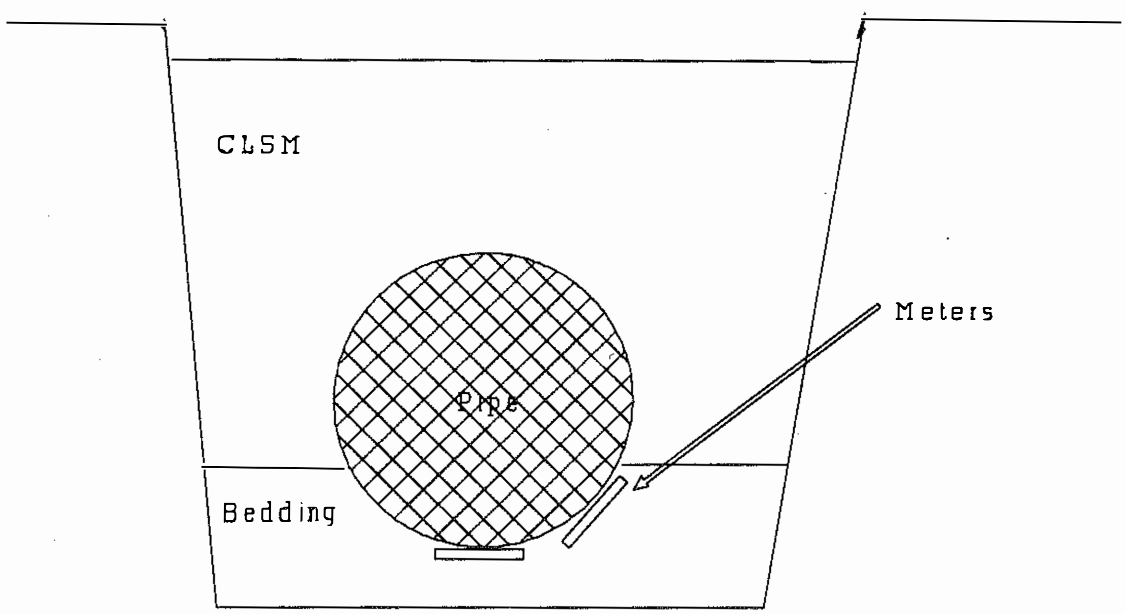

Figure 7. *Pressure meter locations for 36-inch pipe.*

cylinder mold under wet burlap until tested. The open ended mold permitted the escape ~~of free water and the wet burlap maintained the cylinder water content observed in situ.~~

pH

CLSM is an alkaline material having pH values (measured in the field at Site 1) ranging from 11.95 to 12.15. The pH value was determined for several different batches of CLSM at Site 1. Due to the short duration (four days) of work at Site 2 and temporary unavailability of the pH meter, pH was not determined at Site 2.

Compressive Strength

A pocket penetrometer was used in an attempt to monitor short-term unconfined compressive strength changes of the CLSM. Due to the high water content and the granular nature of the CLSM, the pocket penetrometer did not accurately reflect compressive strength, however, strength gains were recorded. As noted previously, CLSM would support a person after 20 to 30 minutes and automobile traffic after approximately one hour but penetrometer data indicated maximum unconfined compressive strength of 2.5 psi after nearly two hours. Short-term changes in unconfined compressive strength, as measured with the pocket penetrometer, of in-situ CLSM are shown in Figure 8.

Moisture Content and Density

CLSM moisture content and density were monitored with a Troxler 3440 series moisture/density gauge and with samples recovered from excavated CLSM. At one trench the Troxler gauge was used to monitor CLSM from the time at which it would support the gauge (approximately 20 minutes) until it had been in place 83 minutes. Data for CLSM which had been in place two and three days were obtained at other sites.

The mix design used at Site 1 yields a moisture content (M.C.) of 18.8 percent. The Troxler gauge indicated a M.C. of 14.3 percent at a depth of six inches at 25 minutes after placement of the CLSM in the trench. The Troxler gauge was left in place for 83 minutes with density and M.C. data recorded several times during that period. CLSM dry density increased from 117.8 to 120.5 pounds per cubic foot and M.C. decreased from 14.3 percent to 12.3 percent during that period. Moisture content and dry density changes with curing are plotted versus time in Figures 9 and 10.

CLSM that was placed in a trench and cured for two and three days before being covered with soil indicated M.C., surface to eight-inch depth, ranging from 7.1 to 8.9 percent and dry density ranging from 116.5 to 121.2 pounds per cubic foot. Density data from various depths (up to eight inches) indicate that density increases with depth. CLSM samples

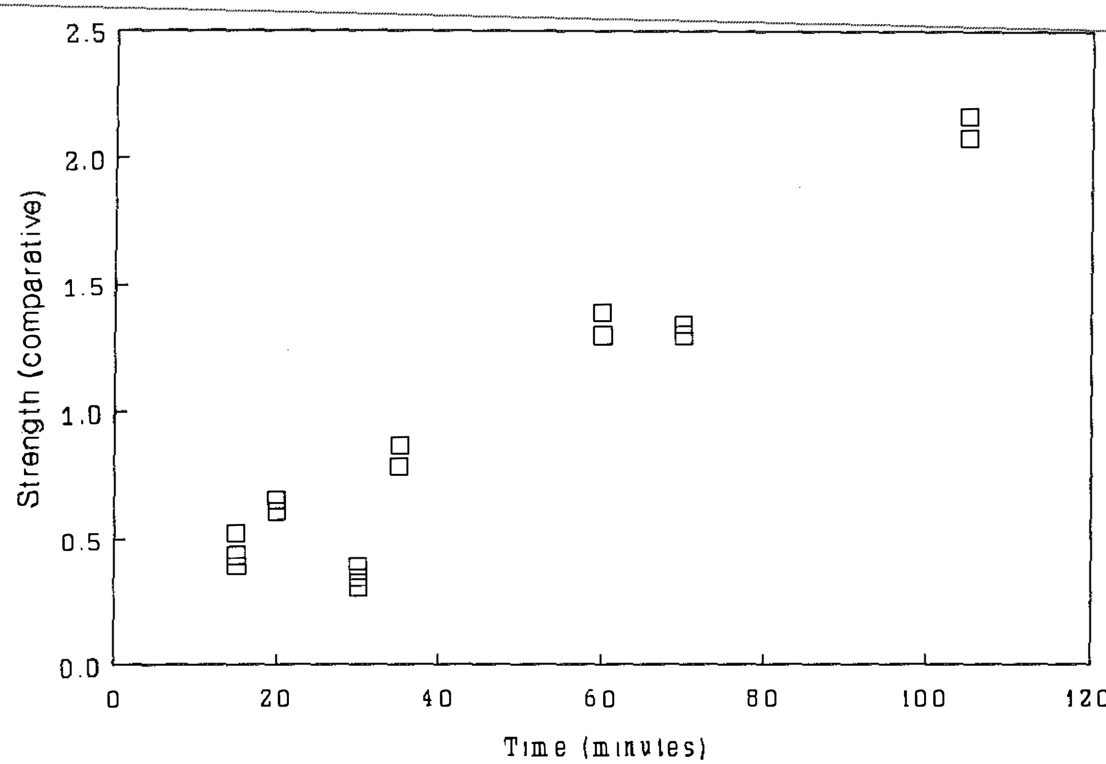

Figure 8. *Short-term changes in CLSM compressive strength as measured with pocket penetrometer.*

recovered from trenches that had been backfilled and covered with soil had moisture contents from 13.5 to 14.0 percent.

Due to the short duration of construction and the fact that trenches were covered with steel plates as soon as they were backfilled at Site 2, field monitoring was limited to observation, photo logging, cylinder casting, placement of stress meters, and location of settlement monitoring points.

Removability

One major concern with the use of CLSM was the removability of the material in the event repairs should be necessary. Due to the installation of some unapproved pipe at Site 1, it was necessary to verify pipe lot numbers by excavating the CLSM. The excavation of CLSM occurred at an age of approximately 150 days. This particular CLSM had a 28-day compressive strength of approximately 85 psi and, from cores taken from excavated material, a 150-day strength of approximately 220 psi. The equipment used was a Case model 680H backhoe. The CLSM was very difficult to penetrate with hand

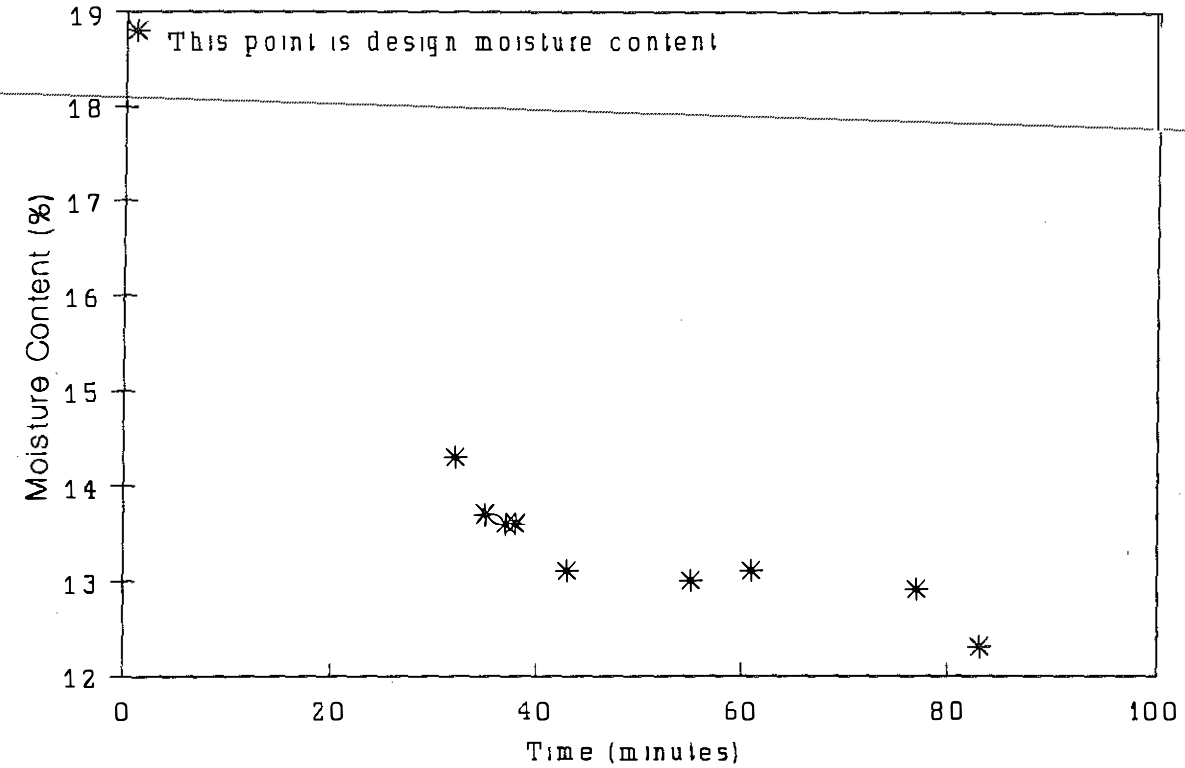

Figure 9. *Short-term changes in moisture content of in situ CLSM.*

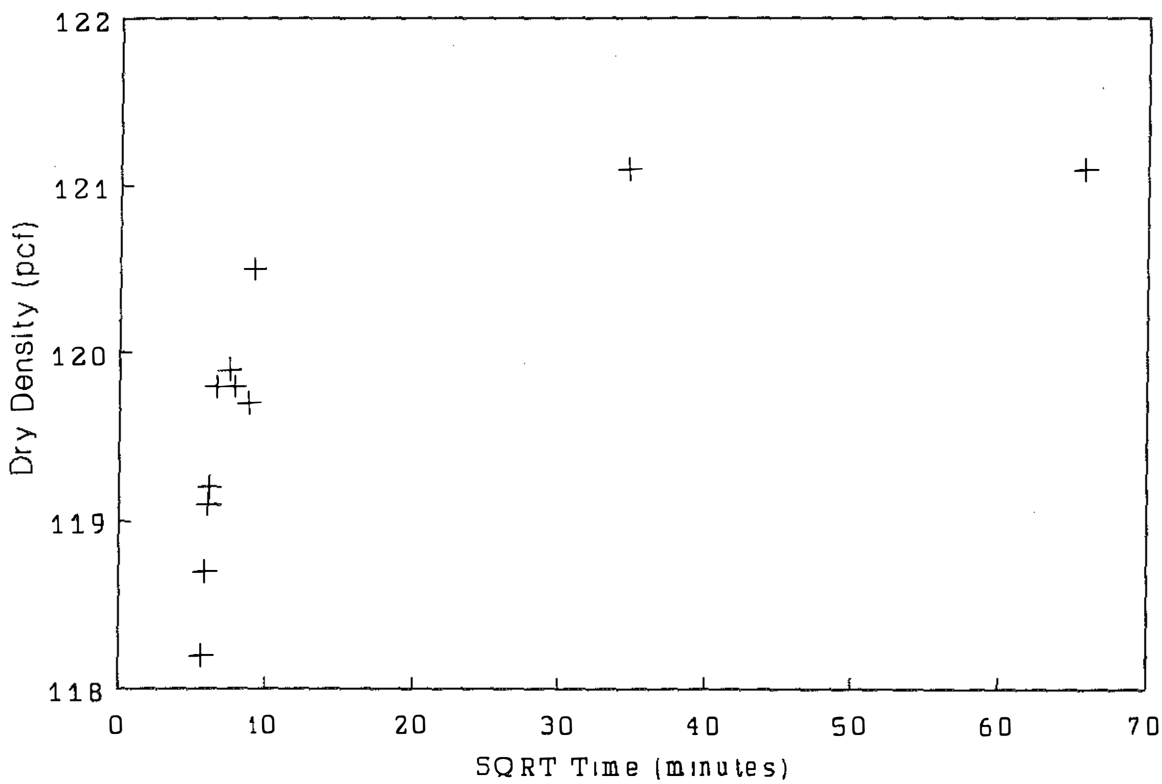

Figure 10. *Changes in dry density of in situ CLSM.*

tools but the backhoe removed the CLSM moderately easy in ten minutes. The length of pipe uncovered was eight feet.

A report (2) issued by Cincinnati Gas & Electric and written by William Brewer of Brewer and Associates addresses removability. An empirical relationship developed by Mr. Brewer incorporates several factors, yields a removability factor (RF), and is expressed as:

$$RF = \frac{5.27TJ\left[1+\left[\frac{IP-D^3}{\sqrt{IPD}}\right]\right]}{SA}$$

where:

RF = Removability factor
T = Equipment type
J = Cutting edge used on the excavating pavement
I = Impact factor
P = Power factor based on equipment used
D = Direction of excavation
A = Area under the stress/strain curve = 0.0094 x [compressive strength]$^{1.4}$ {lb.ft.}
S = Density {pcf}

In Mr. Brewer's relationship, the higher the RF value the more easily the material can be removed.

Compressive strength tests of all cylinders cast from CLSM pours from both Site 1 and Site 2 indicate compressive strength increasing through at least one year. The 28-day compressive strength factor included in Mr. Brewer's relationship does not reflect the ultimate compressive strength of the CLSM. Ultimate strength will determine, with other pertinent factors, the removability of CLSM. A method for predicting ultimate compressive strength is needed.

A method which appears to reasonably predict ultimate compressive strength was developed using cylinder compressive strength test results over an extended period of time. Test results from cylinders cast at Site 1 include eight sets of cylinders that were tested at various ages up to 400 days and with at least two different age breaks per site. Three of the sets exhibited decreased or relatively constant compressive strength after approximately one year. These three sets provide a check of the ultimate compressive strength prediction method.

The method involves plotting compressive strength versus age of the cylinders. The data are typically described by a hyperbolic function. The hyperbolic function is then transformed into a straight line by plotting X-axis values versus (X/Y) values. The inverse slope of the straight line approximates the ultimate compressive strength for the CLSM. The three sets of cylinders which have already achieved ultimate compressive strength confirm the reasonable approximation of this method. CLSM age versus compressive strength is graphed for all sets of cylinders in Figure 11. The curves are converted to hyperbolic functions and plotted versus age in Figure 12. Ultimate compressive strength, as calculated from the inverse slope of each function is shown in Table 1 along with the maximum compressive strength of the three sets which have apparently achieved ultimate compressive strength.

The relationship developed by Mr. Brewer was used to analyze CLSM that was excavated at Site 1. This particular CLSM had a 28-day compressive strength of 85 psi, a 150-day compressive strength of 220 psi, and a predicted (by the above described method) ultimate compressive strength of 513 psi. The material was excavated at 150 days with a 680H Case backhoe. The backhoe bucket was a toothed bucket and the excavation required minimal pounding. The excavation was along the trench and was approximately 12 feet in length with one eight-foot section of pipe completely revealed. Excavation to the pipe required approximately ten minutes and was characterized as moderately easy.

Mr. Brewer's report indicates that a RF of 80 to 100 is easily removable and a RF of 60 to 80 is fairly easily removed. The factors included in the RF relationship as determined by equipment size, excavation direction, etc... along with a density of 120 pcf and a compressive strength of 85 psi yield a RF of 323. Samples obtained at the excavation indicate a density of 120 pcf and compressive strength of 220 psi. Substituting the actual compressive strength for the 28-day compressive strength in Mr. Brewer's Removability Factor relationship yields a RF of 90 which appears a more reasonable estimation of removability. Tests conducted on other cylinders from this set indicate increasing compressive strength and the predicted ultimate compressive strength of 513 psi. CLSM with this compressive strength would be extremely difficult to remove (RF=28) with other parameters held to the actual excavation conditions. Optimizing other parameters, but using the 680H Case backhoe, yields a RF factor of 58. Mr. Brewer's mathematical relationship, parameter tables, and example calculations are included in Appendix C.

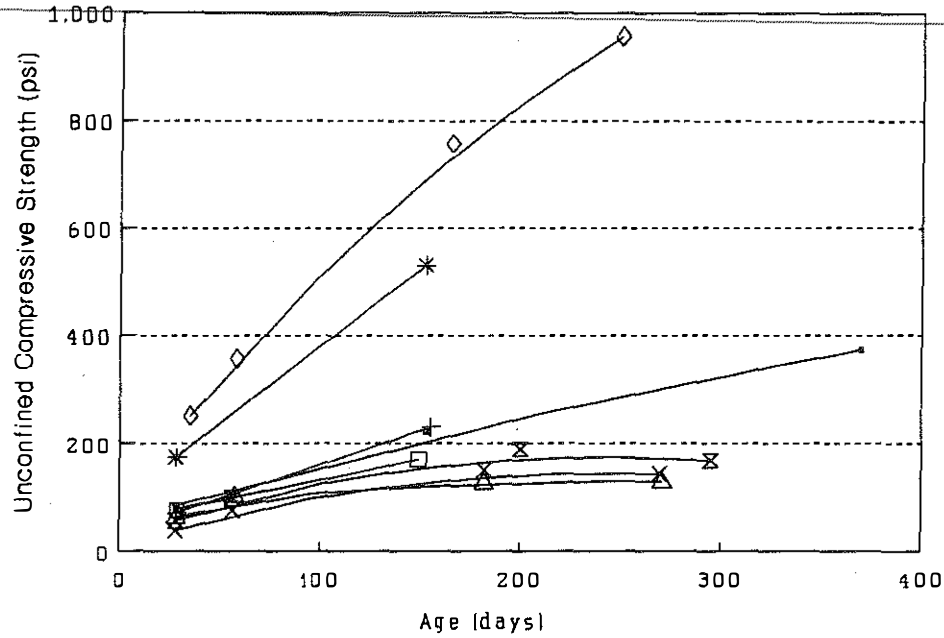

Figure 11. *Compressive strength for sets of cylinders.*

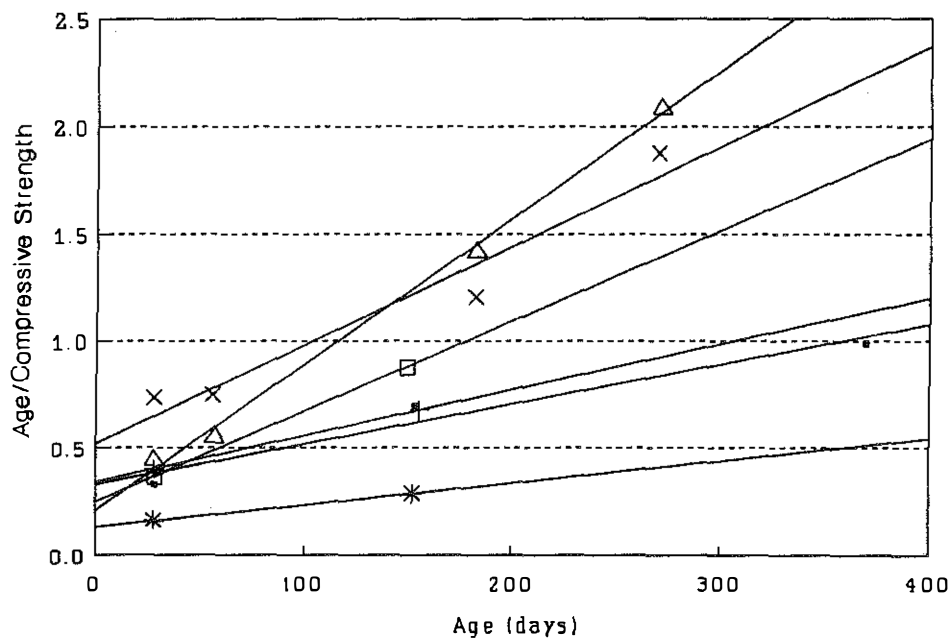

Figure 12. *Compressive strength curves converted to straight lines.*

Pipe Stress

Pressure meters installed under the pipes at Site 1 indicated relatively high pressure when the CLSM was initially placed but the pressure decreased as water bled from the CLSM. Initial pressures ranged from nine to 32 psi but quickly decreased to approximately 50 percent of the peak and have remained relatively constant during the monitoring period. Meters placed either on the top of the pipe or at the CLSM-bedding interface indicate initial pressure spikes up to four psi but quickly decrease to near zero psi and remain at that level. Pressure data for the three culverts having CLSM backfill are shown in Figures 13, 14, and 15.

Meters placed on pipes having conventional backfill (Site 1) indicate no pressure spikes but gradually increasing pressure. Approximately 70 days after the conventional backfill was completed, meters indicated pressures of nine and 47 psi at the top and bottom of the pipe, respectively. Stress data from these meters are shown in Figure 16.

TABLE 1. Compressive strength of sets of cylinders at different curing ages.

Set No.	Age at Test (days)	Compressive Strength at Age of Test (psi)	Predicted Ultimate Compressive Strength of Sample Set (psi)
1	28	85	
	153	220	
	370	374	483
2	28	70	
	155	230	448
3	28	174	
	152	530	898
4	28	77	
	149	170	237
5	28	57	
	56	99	
	200	190	
	295	168	222
6	28	63	
	57	103	
	182	128	
	271	130	227
7	35	250	
	58	357	
	165	757	
	250	955	2,200
8	28	38	
	56	75	
	182	151	
	270	144	146

The two meters that are functioning properly at Site 2 are located under the pipes and both indicate very low pressure on the pipe. Initial data for both meters were obtained prior to placement of the CLSM backfill. Data obtained immediately after placement of the CLSM indicated reduced pressure. This is probably a result of buoyant forces of the CLSM. Subsequent data indicate increasing pressure but at negligible levels. Stress data for the functioning meters at Site 2 are shown in Figure 17.

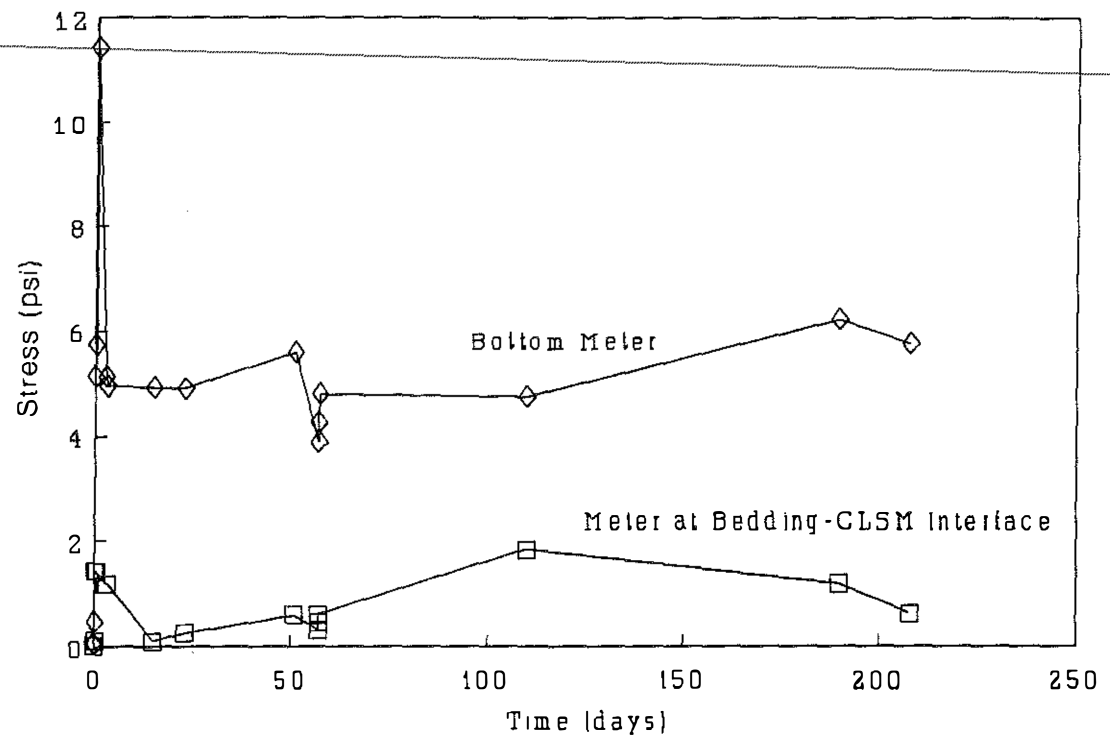

Figure 13. *Pipe pressure for 36-inch pipe at Site 1.*

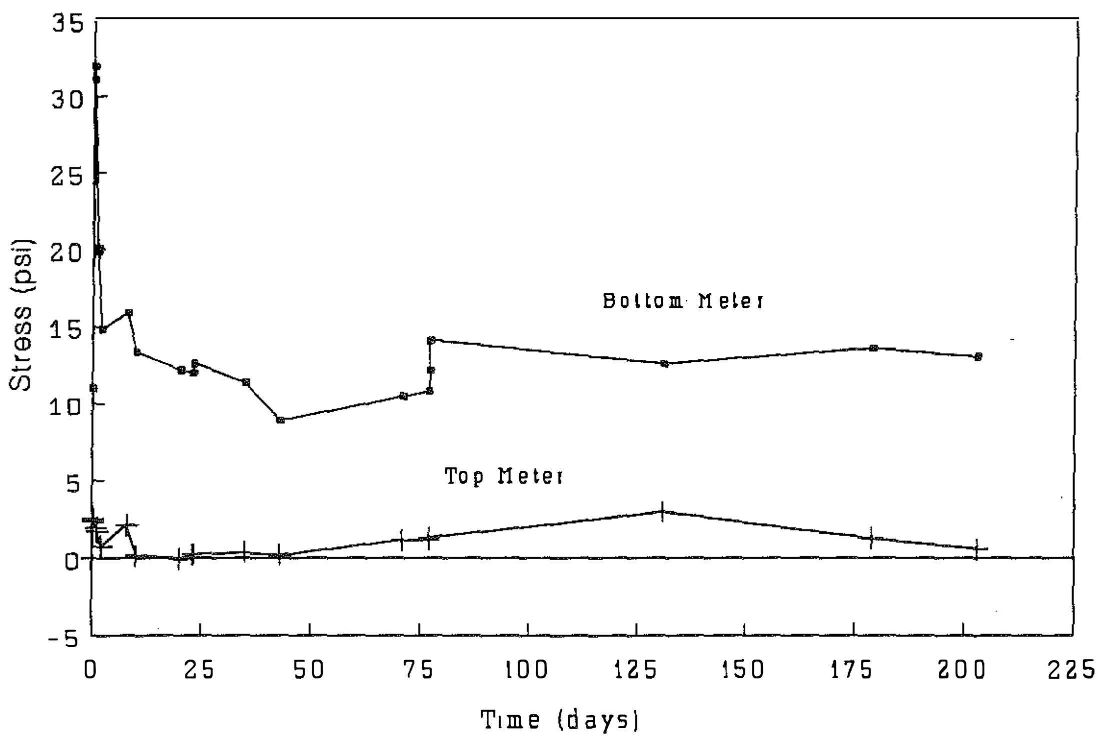

Figure 14. *Pipe pressure for elliptical pipe at Site 1.*

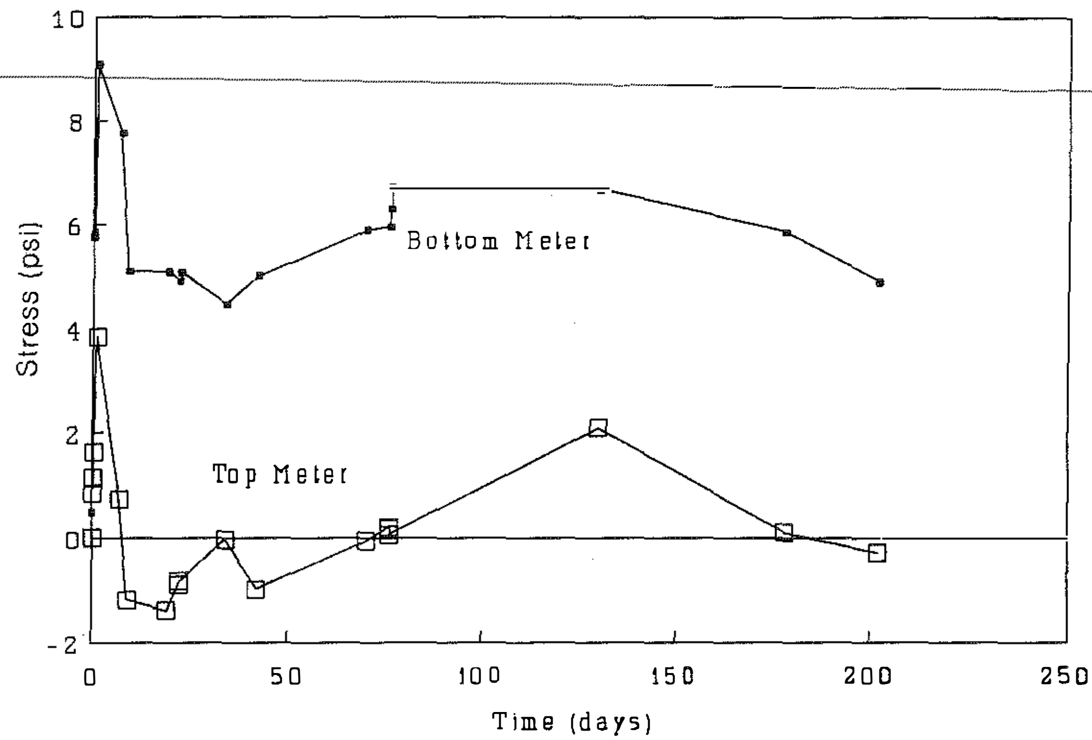

Figure 15. *Pipe pressure for 24-inch pipe at Site 1.*

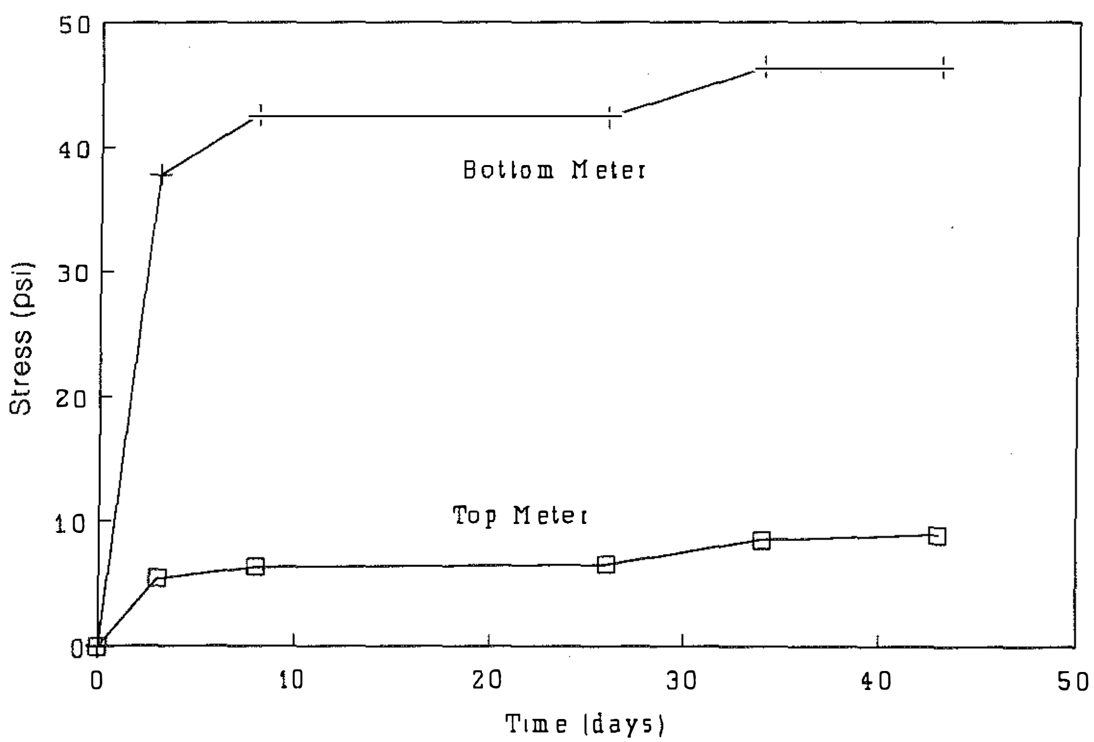

Figure 16. *Pressure on pipe at Site 1 with conventional backfill.*

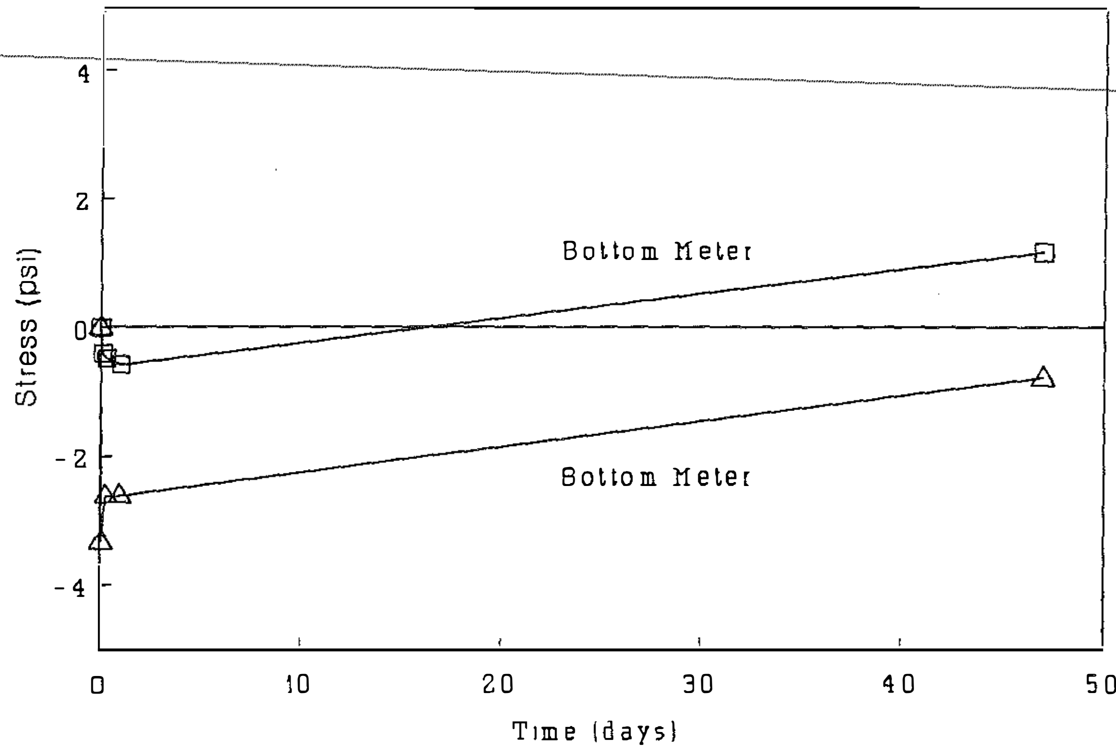

Figure 17. *Pipe pressure at Site 2.*

To assess the influence of traffic on pipe stress, vehicles of known weight were used to load the instrumented pipes. A small truck, axle weight 2,490 pounds, and a larger truck, axle weight of 14,640 pounds and total weight of 20,680 pounds, were used. The 1,980 pound axle was placed on the CLSM backfill at the 24-inch and the elliptical pipe 22 days after placement of the CLSM. The top meters did not reflect the load. The bottom meters indicated a minimal load increase of 0.1 to 0.2 psi. These results are seen at 22 days in Figures 14 and 15. The large truck was placed both astraddle the CLSM backfill and with the 14,640 pound axle directly on the CLSM backfill. The results of this loading are seen in Figures 14 and 15 at 76 days and in Figure 13 at 57 days. Meters on the top of the pipes, 24-inch and elliptical, indicate no load increase. The meter at the bedding-CLSM interface indicated an increase of 0.2 psi. Meters on the bottom of the pipes indicated load increases up to 3.3 psi.

Safety

One important factor which is difficult to assign a monetary value to is safety. In contrast to many pipe laying projects, the use of CLSM, at Site 1 in particular, permitted backfilling of trenches within minutes of the time that the pipe was in place. Trenches seldom remained open overnight and with proper planning CLSM may be placed sufficiently early in the afternoon so that sufficient curing may occur to minimize roadway construction hazards.

Sampling

An attempt was made using a portable coredrill to recover samples of CLSM that had been in place for approximately 30 days. The attempt was not successful. The use of water to remove the cuttings destroyed the core and without water the drill locked in the CLSM. Also, an attempt to obtain Shelby tubes was not successful. High-strength tubes did recover short CLSM samples but the samples were fractured. Since CLSM continues to gain strength for several months, coring at a later date may be feasible.

Summary of Field Evaluation

Observation of the use of CLSM as a trench backfill and limited field testing indicates that CLSM is an effective backfill material when used properly. Project conditions varied greatly, therefore CLSM performance requirements, acceptance criteria, and mix design may vary. CLSM as used at Site 1, Site 2 and observed at other agency sites was a flowable, controlled density material. At Sites 1 and 2, some mix design changes, primarily the addition of water, were necessary to obtain a satisfactory product. CLSM appears to work best as a very wet, flowable material, such as shown in Figures 18 and 19. Very flowable CLSM reduces the time required to obtain workable density and strength and assures filling of all voids in trench walls and around the pipes. Higher water content tends to reduce compressive strength and as a trench backfill low compressive strength is desirable.

Mix design at Sites 1 and 2 included 50 and 40 pounds of portland cement per cubic yard, respectively. Both mixes included 300 pounds of fly ash and 2,750 pounds of natural river sand per cubic yard. These mixes tend to yield 28-day compressive strength from 50 to 150 psi. Dry density tends to range from 120 to 122 pounds per cubic foot and in-situ moisture content tends to be from 12 to 14 percent.

Placement of CLSM proceeded with few problems at Site 1. At Site 2, there were some problems in achieving flowability and backfill side slope requirements but the problems were resolved. The addition of water assured good pipe encasement and the use of sand bags stepped back with increased elevation met side slope requirements.

The Special Notes defining CLSM acceptance criteria differed from Site 1 to Site 2. The Special Note for Site 1 specified mix design, bleed time, and cylinder casting. The Special Note for Site 2 only specified that CLSM backfill was to match the existing side slope. The inclusion of flow and bleed time criteria assists inspectors in determining acceptability of the CLSM.

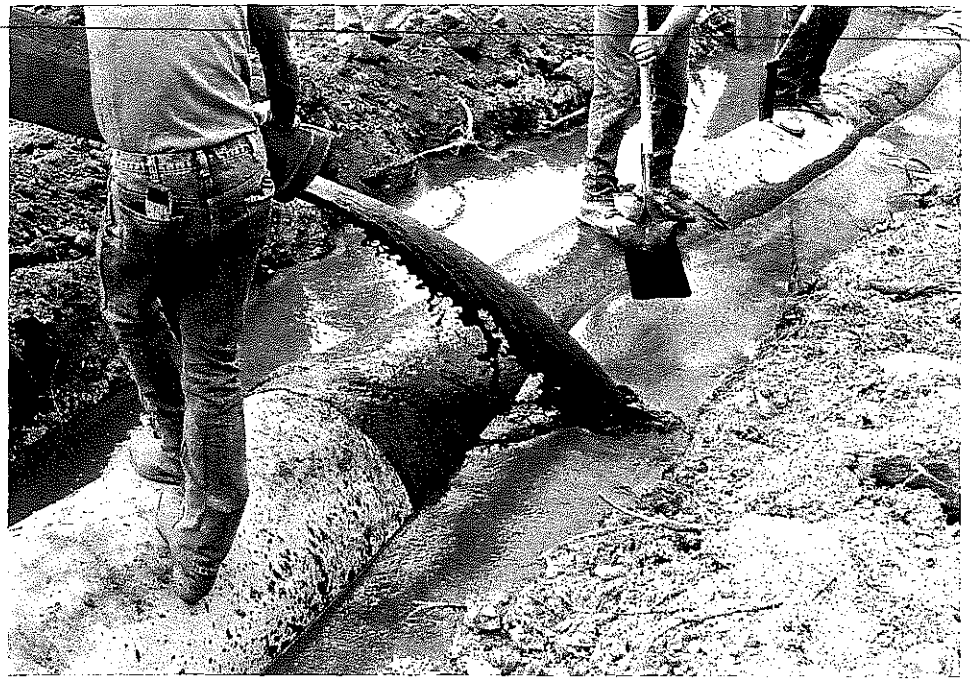

Figure 18. *CLSM at Site 1 after adjusting the mix. Material was flowable and workers with shovels were not used after first day.*

Figure 19. *CLSM at Site 1 with visible channels from bleed water runoff and fine material washed to the surface by bleeding.*

Cylinders were cast to determine shrinkage, density, and a variety of laboratory determined engineering characteristics. CLSM cylinders are extremely sensitive to disturbance, and therefore should be moved with great care and only after several days of curing. CLSM contains very small amounts of cement and does not develop significant cohesion for some time. Cylinders should be cured in the laboratory in a wet environment with both ends of the mold removed.

The inclusion of fly ash enhances long-term strength gains in CLSM. The fly ash also enhances flowability and density. Long-term strength gains are not desirable in a trench backfill, therefore cement quantities should be minimized. Compressive strength significantly affects removability of CLSM. A mathematical relationship developed by William Brewer evaluates removability when actual compressive strength is included rather than 28-day compressive strength. CLSM having an ultimate compressive strength greater than 500 psi will be difficult to remove from a trench. A method for predicting ultimate compressive strength from early compressive strength tests has been described herein.

Shrinkage of CLSM with curing tends to be two to three percent of the original volume, as calculated from cylinders cast at the job site. Most of this volume change occurs during bleeding, while the CLSM is still pliable, therefore no shrinkage separation from trench walls has been observed.

Stress meters placed on pipe surfaces indicate that long-term pressure on CLSM backfilled pipes is minimal. As soon as CLSM is placed, pipe pressure increases to the weight of the backfill but decreased with bleeding. Meters placed on top of pipes indicate no significant pressure after curing of the CLSM. Meters on pipes having cradle bedding indicate low pressure. Pipes having conventional backfill, compacted layers of manufactured sand, have much higher pressure, up to 47 psi, and pressure continues to increase.

CLSM bleed times were observable and within acceptance criteria at Site 1. Bleed time was not included in acceptance criteria at Site 2 and flowability and bleed time were variable at that site. The cylinder flow test was difficult to perform and was abandoned at Site 1. The flow test should continue to be used with care taken to continually agitate the CLSM until deposited in the cylinder.

The use of CLSM appears to greatly increase productivity. The use of manufactured sand as conventional backfill for the control section increases trench backfill time by a factor of five to six. Use of CLSM permits the contractor to reduce form work around boxes. Labor is reduced from typically three persons to one person with the use of CLSM. Inspection is reduced in that backfill time is reduced and compaction of backfill need not be tested.

Settlement monitoring points have been established on the pavement surfaces where CLSM was placed.

LABORATORY EVALUATION

Compressive Strength

The 28-day compressive strength of approximately 50 psi does not designate the target as a maximum or minimum nor does it include a range of acceptance. Most inspection personnel are accustomed to target compressive strength as a minimum strength. In the case of CLSM use as a trench backfill, compressive strength should be within a narrow range of the target strength or a maximum strength should be considered.

At Site 1, 28-day compressive strength of cylinders cast by both KTC and KDOH personnel ranged from 36 to 668 psi. CLSM compressive strength (at 28 days) tended to be more variable early in the project. As construction personnel and the CLSM supplier gained experience with the material and the project, CLSM 28-day compressive strength became more consistent with a range of 36 to 150 psi over the last seven months of the project. Summaries of KDOH and KTC cylinder compressive strength data are shown in Appendices D and E, respectively.

The KTC cylinder casting procedure was to cast several cylinders for each casting so as to have cylinders available for compressive strength tests over an extended time. This was deemed important in order to monitor long-term strength changes and their impact on removability. Cylinders from Site 2 have not aged sufficiently to produce long-term data but cylinders from Site 1 have been tested at ages in excess of one year. Cylinders tested to date indicate continued strength gains for all sets of cylinders tested. CLSM compressive strength versus time for sets of cylinders from Site 1 was shown in Table 1.

Cylinders from Site 2 were cast from four pours. The cylinders were cast using the same procedure as at Site 1, except that filled cylinder molds were lightly tapped. When removed from the mold, cylinders from Site 2 exhibited many voids and clear delineation of layers which is probably a result of the dry nature of the CLSM at this site. The cylinders would readily separate along the layer surfaces. Compressive strength ranged from 36 to 57 psi for three pours and was 164 psi for the other pour. More cylinders (16 to 17) were cast in each group at Site 2 than at Site 1 to permit testing over an extended curing time.

Shrinkage

Initially, the procedure for casting cylinders followed the Special Note in that molds were topped off after approximately 30 minutes. KTC personnel began leaving the cylinders to cure with the CLSM originally used to fill the mold. This permits monitoring of volume loss or shrinkage of the CLSM. Volumetric shrinkage calculated from 25 cylinders ranged from 0.5 percent to 5.1 percent and averaged 3.1 percent.

Resilient Modulus

Because CLSM is often used as a base for pavement structures, two samples were tested for resilient modulus prior to the unconfined compression test. The modulus determination is a nondestructive test and did not affect the compressive strength results. The compressive strengths of the cylinders were 128 and 89 psi and the resilient moduli were 35,000 and 46,000 psi, respectively. Those moduli are higher than the modulus a soil subgrade would normally exhibit except under the very best of conditions. The high moduli indicate that CLSM provides an excellent base for pavement structures. Additional modulus tests will be conducted.

Permeability

Three CLSM samples were tested for permeability using an Army Corp of Engineers constant head method (3). Two samples were extracted from Shelby tube samples of CLSM and the third was a cast cylinder. The Shelby tube samples had permeabilities of 1.09×10^{-7} and 5.47×10^{-5} centimeters per second and the cylinder had a permeability of 1.01×10^{-6} centimeters per second. While there were considerable variation in the permeability of the three samples, this limited testing indicates that CLSM is fairly impermeable.

Triaxial Tests

One of the most positive aspects of CLSM is the absence of densification of the product after a short curing period. Two major factors contributing to this is the densification achieved during bleeding and the cohesion achieved with the use of cement and fly ash. A series of undrained triaxial tests was conducted (on samples from Site 1) to determine the internal friction angle and cohesion of CLSM. Test results indicate an average internal friction angle of 39.5 degrees and cohesion of 3.6 psi.

Moisture/Density Relationship

Laboratory mixes of the mix designs from both sites were used to determine moisture/density relationships. There was little difference in test results for the two mixes having moisture contents of 10 percent and 9.5 percent and dry densities of 126.3 and 126.5 pounds per cubic foot for Site 1 and Site 2, respectively.

Mix Design

CLSM is a material that may be used for many different applications and therefore might be designed with different characteristics. For use as a trench backfill, CLSM might still have varied requirements such as flowability, ultimate compressive strength, early bearing capacity, or other properties, depending upon the specific project. Another reason to consider alternative mix designs is to reduce the cost of CLSM since cost would be the primary factor inhibiting increased use of CLSM. CLSM, as used in observed utility projects and at both sites involved in this study, generally required low ultimate strength, fast early strength and average flowability.

A laboratory study of the use of manufactured limestone sand (MLS) as a CLSM filler in lieu of natural river sand (NRS) was conducted. Previous studies indicated an increased CLSM compressive strength with MLS as the filler; therefore, a CLSM mix with NRS was used as a control mix and four MLS mixes were designed. The MLS mixes used the same fly ash content but used 30 and 40 pounds of cement per cubic yard as compared to the 50 pounds cement used with NRS mixes. Water content was adjusted to provide an eight-inch puddle during the cylinder flow test. Due to seasonal and source variations in MLS gradation, two gradations, fine and coarse, were used. The various mix designs are given in Table 2. The gradations of MLS and NRS are shown in Figure 20.

Parameters of particular interest were, compressive strength, time of development of strength, flowability, bleed time, density, and settlement. Through trial and error, a technique for simulating field conditions was developed. The technique involved mixing relatively small quantities in a mixing bowl, and continue agitation until discharging the mix into cylinder molds or into a burlap lined pan. The burlap lined pan simulated trench conditions in that bleed water could escape the CLSM surface.

The general conclusions drawn from the laboratory mix design evaluation were that CLSM with MLS as the filler achieves greater ultimate compressive strength, has significantly longer bleed time, takes significantly longer to achieve sufficient bearing capacity to accept traffic, and has greater settlement or shrinkage over an extended period as compared to CLSM with NRS filler. All of these characteristics make NRS a

TABLE 2. Laboratory mix design weights.

SSD Weights of Mix Designs per Cubic Yard

Aggregate Grading	NRS	MLS Coarse	MLS Coarse	MLS Fine	MLS Fine
Cement (lbs)	50	40	30	40	30
Fly Ash (lbs)	300	300	300	300	300
Sand (lbs)	2,750	2,760	2,770	2,760	2,770
Water (lbs)	480	480	480	619	619
Total (lbs)	3,580	3,580	3,580	3,719	3,719

Batch Weights of Mix Design per Cubic Yard
(Adjusted for Free Moisture Content and Absorption of Sand)

Aggregate Grading	NRS	MLS Coarse	MLS Coarse	MLS Fine	MLS Fine
Cement (lbs)	50	40	30	40	30
Fly Ash (lbs)	300	300	300	300	300
Sand (lbs)	2,873	2,737	2,747	2,737	2,747
Water (lbs)	357	504	504	642	642
Total (lbs)	3,580	3,581	3,581	3,719	3,719

more acceptable filler for CLSM to be used in highway construction. Other possibilities which were not included in this analysis might be mechanical densification (vibration) or chemical additives to hasten bleed time and densification of CLSM with MLS filler. Graphs of the monitored engineering characteristics of the CLSM mixes used in the mix design analysis are included in Appendix F.

While the cylinder flow test proved difficult to use in the field, it proved to be a consistent and useful test under laboratory conditions. The flow test technique used in the laboratory, small CLSM quantities and continued agitation, might be applied to field flow testing.

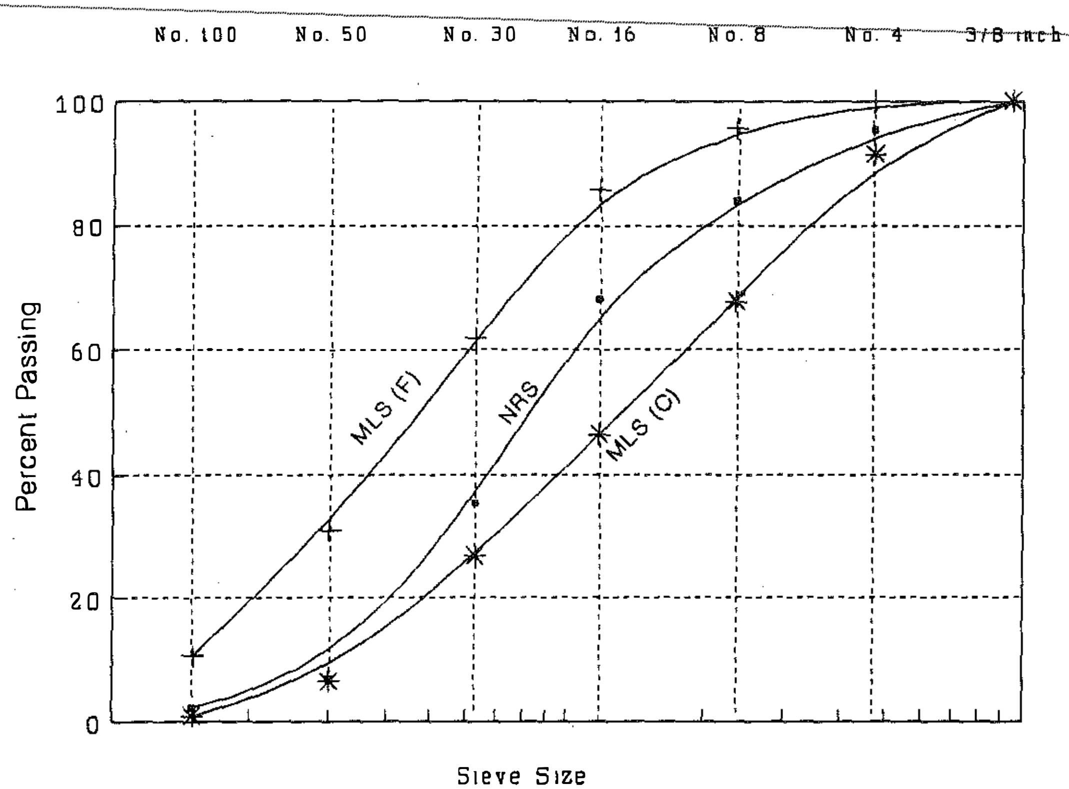

Figure 20. *Gradation of manufactured limestone sand (MLS) and natural river sand (NRS) used in laboratory mix design analysis.*

Summary of Laboratory Analyses

Test cylinders were cast by both KTC and KDOH personnel at Site 1 and by KTC personnel at Site 2. KDOH cylinders were tested for compressive strength and KTC cylinders were tested for various properties. Sets of cylinders from Site 1 usually consisted of six to eight cylinders. At two cylinders per break, compressive strength tests at three time intervals is the norm. Additional cylinders were cast at Site 2 to allow testing over additional time intervals.

Laboratory testing of both KTC and KDOH cylinders from Site 1 indicated that 28-day compressive strengths ranged from 36 to 668 psi. As construction personnel and the CLSM supplier gained experience with the product, the 28-day compressive strength became more consistent. Over the last seven months of the project, 28-day compressive strengths ranged from 36 to 150 psi and the average 28-day compressive strength decreased from 91 to 53 psi.

Other properties determined from laboratory tests of cast cylinders were; average shrinkage of 3.1 percent, resilient moduli of 35,000 and 46,000 psi, permeability ranging from 5.47 x 10^{-5} to 1.09 x 10^{-7} centimeters per second, internal friction angle of 39.5 degrees, cohesion of 3.6 psi and optimum moisture/density conditions of approximately 10 percent moisture and dry density of 126.5 pounds per cubic foot.

A laboratory mix design analysis addressed the use of manufactured limestone sand (MLS) as a CLSM filler as compared to the normal natural river sand (NRS) filler. Findings were that CLSM with MLS filler exhibits greater ultimate strength, significantly longer bleed time, greater settlement or shrinkage, and requires significantly more time to develop sufficient bearing capacity to accept traffic. The minimal reduction in costs would not negate all the performance liabilities of MLS as a CLSM filler for highway construction purposes.

COST COMPARISON

The cost comparison between CLSM and conventional backfill (manufactured sand) was performed on a cross-drain trench at Site 1. The dimensions of the trench were: 28-foot length, six-foot height, and an average of six-foot width. The factors used in the cost analyses were labor (including fringe benefits), equipment (including fuel, lubricants, filters), and materials (including handling). Other factors which were difficult to assign cost to were not included in the analyses. Liability, remedial work, productivity, inspection, and testing are all factors which will influence the final cost but were not included in the cost analyses. All the factors not included will tend to increase the overall cost effectiveness of CLSM.

The conventional backfill material was manufactured sand. The cost of labor for conventional backfill placement was calculated based on two laborers, one equipment operator, and one supervisor. Only one half of the supervisor's cost was used due to significant amounts of his time being devoted to other work. The total cost of labor, including fringes, was $314.63. The equipment cost was based on an hourly rate that was derived from the cost of monthly rental. The equipment involved was one backhoe and two mechanical tampers. The total equipment cost, including fuel, lubricants, and filters, was $204.14. The amount of material used was determined by using the volume of the trench, minus pipe volume, and the density achieved. The total material cost, including handling, was $153.67. Based on these calculations, the total for backfilling the trench with manufactured sand was $672.44.

The cost for placing flowable fill was calculated based on the cost of material and the cost of labor. The cost of transporting the material was included in the price per cubic yard. The total cost for the material was $928.33. The labor cost, based on the use of one laborer, was $10.38 including fringes. The total cost to place flowable fill was $938.71. Using only the immediate costs, CLSM costs approximately $9.51 per foot of pipe more than conventional backfill.

This cost comparison was generated using identical volumes for both backfill materials. However, in actuality, the volume of a trench where flowable fill is used is significantly less than the volume of a trench where conventional backfill is used. When using conventional backfill, there is much more room needed in the trench because laborers have to be in the trench to compact the backfill material. The cost analyses were reevaluated for CLSM backfill using trench dimensions of 28 feet-length, six feet-height, and a 4.5 foot-width. The only dimensional change occurs in the width of the trench, and in this example allows for a one-foot clearance on each side of the pipe. This reduction in trench width reduces the total cost of the CLSM backfill to $669.88. Therefore, with reduced trench width, the CLSM backfill material is at least equivalent in costs to the manufactured sand backfill.

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2. Brewer and Associates, "Factors Governing The Removability Of Controlled Low Strength Material - Controlled Density Fill - (CLSM-CDF), Cincinnati Gas And Electric Company, Cincinnati, Ohio, May, 1991.

3. US Army Corp of Engineer, 1980, Laboratory Soils Testing, Engineer Manual EM 1110-2-1096, Washington, DC.

APPENDIX A

SPECIAL NOTE FOR USE OF
FLOWABLE FILL AS PIPE BACKFILL
BRECKINRIDGE LANE
LOUISVILLE

I. GENERAL

In lieu of the selected fine soil, sand or No. 10 coarse aggregate required by the current issue of the Standard Drawings as backfill material for pipe, flowable fill shall be used. The flowable fill shall extend from the top of the compacted sand bedding to a minimum of 12 inches and a maximum height of 48 inches above the outside top of the pipe, if the trench depth permits. Flowable fill shall be a minimum of 12 hours of age prior to the addition and compaction of any material above it.

II. MATERIALS

Ingredient materials shall meet the requirements specified in the following sections of the Standard Specifications:

Portland Cement, Type I	801
Sand	804
Fly Ash, Class F	844
Water	803

The flowable fill shall be initially mixed in the following proportions per cubic yard:

Cement (Minimum)	50 lbs
Fly Ash	300 lbs
Sand (550)	2,750 lbs
Water (Maximum)	500 lbs

To expedite settlement of the flowable fill it will be necessary for bleed water to appear on the surface within five ten minutes after placement. A delay in bleeding indicated there are too many fines in the mixture, so the fly ash quantity shall be reduced in increments of 50 pounds until mixture is bleeding freely. Approximately 60 pounds of sand shall be added to replace each 50 pounds increment of fly ash to maintain the original yield. The flowable fill is too dry when cracks develop as it flows into place.

A set of test cylinders shall be cast for each 100 yards of flowable fill. Cylinders shall not be rodded, but the sides of the mold shall be tapped lightly after each layer. The test cylinders should be allowed to bleed for about 30 minutes, refilled, and then covered with a sheet of tough durable impervious plastic. Secure the plastic in place around the mold, within one inch of the top, with a rubber band or string prior to covering with wet burlap.

Remove the burlap after 24 hours and cure at 60° to 90° F, in the shade, until 28 days old. Then remove the plastic covering and mold and perform compressive strength test. The average of the 28-day compressive strength tests is expected to be approximately 50 psi.

III. CONSTRUCTION PROCEDURES

Flowable fill shall be delivered in a specification truck mixer to insure that the mixture is in suspension when placed. Agitation is required during transportation and waiting time. Subsidence may occur if the mixer is not agitated. Normally, a trench can be backfilled directly from the truck chute or a pump may be used.

Certain types of pipe may float, therefore backfilling may have to be done in lifts or else the pipe will need to be anchored. Backfilling in lifts is generally more applicable to long lines of pipe, allowing time for a substantial amount of the water to dissipate prior to applying the next lift. Anchors can be made of small lumber, metal straps, etc., and must be adequately spaced. For larger diameter pipe, it may be possible to maintain a surge of flowable fill on top of the pipe to help prevent floating. Generally floating is not a problem after the level of the backfill is above the springline of the pipe. The contractor is responsible to take whatever action is necessary to insure that the pipe remains in the correct horizontal position and at the specified elevation.

IV. BASIS OF PAYMENT

The cost of furnishing and placing flowable fill as backfill material for pipe will be incidental to the unit cost per linear foot for the type, class, and size of pipe.

APPENDIX B

SPECIAL NOTE FOR USE OF
FLOWABLE FILL AS PIPE BACKFILL
RICHMOND ROAD
FAYETTE COUNTY

I. GENERAL

Flowable fill shall be used in lieu of the selected fine soil, sand or No. 10 coarse aggregate required by the current issue of the Standard Drawings as backfill material for pipe. The flowable fill shall extend from the top of the pipe bedding to 12 inches below the existing pavement. Flowable fill shall be a minimum of three hours of age prior to the addition and compaction of any material above it.

II. MATERIALS

Ingredient materials shall meet the requirements specified in the following sections of the Standard Specifications:

Portland Cement, Type I	801
Sand	804
Fly Ash, Class F	844
Water	803

The flowable fill shall be initially mixed in the following proportions per cubic yard:

Cement (Minimum)	40 lbs
Fly Ash	300 lbs
Sand	2,750 lbs
Water (Maximum)	500 lbs (60 gallons)

To expedite settlement (etc.).

III. CONSTRUCTION PROCEDURES (ADDITIONS)

For part width pipe placement, some manner must be devised to allow a proper connection of the second section of pipe to the pipe previously encased in flowable fill. The flowable fill must conform to the slope of the existing roadway shoulder.

IV. METHOD OF MEASUREMENT

The flowable fill will be measured using the average trench width, not to exceed two feet plus the diameter of the pipe, times the average depth of flowable fill. The volume inside the pipe will be subtracted from this calculated flowable fill using the nominal diameter of the pipe.

V. BASIS OF PAYMENT

The cost of furnishing and placing flowable fill as backfill material for pipe will be paid for at the contract unit price per cubic yard. Payment shall be full compensation for all materials, equipment, labor and incidentals necessary to complete the work.

APPENDIX C

REMOVABILITY FACTOR

The following is a relationship developed by William Brewer that relates density, compressive strength, strength and type of equipment, direction of excavation, cutting edge, and amount of impact used.

$$RF = \frac{5.27TJ\left[1+\left[\frac{IP-D^3}{\sqrt{IPD}}\right]\right]}{SA}$$

The above equation gives the Removability Factor (RF), where:

RF = Removability Factor
T = Equipment Type
J = Cutting Edge used on the excavating pavement
I = Impact Factor
P = Power Factor based on equipment used
D = Direction of excavation
A = Area under the stress/strain curve = 0.0094 x (compressive strength)$^{1.4}$ {lb.ft.}
S = Density {pcf}

Cutting Edge	(J)	Impact	(I)	Equipment	(T)
Blade	50	Low	10	Hand Tool	10
Tooth	100	Average	20	Air Spade	30
Point	150	High	30	Backhoe	50
				Clam Bucket	20
				Dragline	25

Power Factor	(P)
Low	1
Average	5
High	10

Direction of Cut	(D)
Along trench	2
Across trench	1

The following are the ranges of removability:

RF value	Removability
0 - 20	Unable to excavate
20 - 40	Extremely difficult to remove
40 - 60	Removal with difficulty
60 - 80	Fairly easy to remove
80 - 100	Easy removal

FIELD CASE EXAMPLE

In the report issued by Brewer and Associates on the removability of CLSM (see references), the 28-day compressive strength was used in the empirical relationship for the removability factor. It is recommended, however, that the ultimate compressive strength (calculation of the ultimate compressive strength is contained in the Removability section) be used in this calculation. The following example is one basis for the recommendation.

During the construction on Breckinridge Lane, it was necessary for a section of pipe to be uncovered and identified. Samples of the flowable fill that were 150 days old were obtained during excavation. The samples had an average compressive strength of 220 psi. Cylinders cast when the trench was backfilled had an average 28-day compressive strength of 85 psi. The ultimate compressive strength was approximately 513 psi, as estimated using the relationship developed in this report.

Using the tables on the previous page, input variables for the removability factor equation were: J = 100, I = 16, T = 50, P = 6, D = 2. When the 28-day compressive strength (85 psi) was used, a RF value of 342 was obtained. Next, the actual compressive strength (220 psi) at the time of removal was used and the RF value was 90. Finally, the calculated ultimate compressive strength was used and this yields a RF value of 28. Some of the variables could be maximized on the last calculation; ie.-- since RF = 28, means that removal would be extremely difficult, the machinery would probably change it's direction of cut to "Across the trench" (D = 1) and would have the highest impact value (I = 30). Using these values and 513 psi for compressive strength, a RF value of 54 was obtained.

The RF value and ranges of removability are useful and accurate; however, some of the variables involved are very subjective and hard to estimate. The actual removability of the flowable fill may be obtained using the actual compressive strength. However, in most cases it is not known when removal will have to occur, it may be months or years. For this reason, the ultimate compressive strength value should be used to determine the amount of difficulty that might be encountered in removal.

APPENDIX D

COMPRESSION TEST RESULTS
OF KDOH CYLINDERS

DATE CAST	AGE AT TEST (DAYS)	COMPRESSIVE STRENGTH (psi)
09/03/91	28	105
09/06/91	28	250
09/09/91	28	88
09/12/91	28	100
09/13/91	28	65
09/16/91	28	65
09/17/91	28	100
09/19/91	28	80
09/20/91	28	60
09/23/91	28	Destroyed
09/24/91	28	85
09/26/91	28	185
09/27/91	28	225
10/03/91	28	50
10/04/91	28	195
10/10/91	28	Destroyed
10/14/91	28	95
10/16/91	28	65
10/17/91	28	60
10/18/91	28	55
10/21/91	28	130
10/22/91	28	40
10/24/91	28	70
10/25/91	28	Destroyed
10/29/91	28	105
10/31/91	28	175
11/01/91	28	125
11/05/91	28	Destroyed

DATE CAST	AGE AT TEST (DAYS)	COMPRESSIVE STRENGTH (psi)
11/07/91	28	Destroyed
11/08/91	28	280
11/12/91	28	Destroyed
11/13/91	28	140
11/14/91	28	Destroyed
11/19/91	28	115
11/21/91	28	668
11/25/91	28	163
11/26/91	28	243
12/03/91	28	270
12/04/91	28	180
12/06/91	28	210
12/09/91	28	135
02/22/92	28	100
02/25/92	28	Destroyed
02/26/92	28	60
02/27/92	28	65
03/02/92	28	135
03/06/92	28	Destroyed
05/14/92	28	90
08/13/92	28	Destroyed
08/17/92	28	Destroyed
08/19/92	28	150
08/20/92	28	60
08/21/92	28	115
09/01/92	28	Destroyed
09/11/92	28	100

APPENDIX E

COMPRESSION TEST RESULTS
OF KTC CYLINDERS

DATE CAST	AGE AT TEST (DAYS)	UNIT WEIGHT (lbs/ft^2)	COMPRESSIVE STRENGTH (psi)	MOISTURE CONTENT (%)
09/03/91	28	133.3	69	
09/03/91	28	131.3	71	
09/03/91	155	119.7	230	
09/06/91	28	130.4	172	
09/06/91	152	120.6	530	
09/06/91	466	130.2 *	295	12.4
09/09/91	28	134.4	75	
09/09/91	28	136.0	78	
09/09/91	149	120.1	170	
09/09/91	463	134.6 *	85	13.2
09/12/91	29		88	10.0
09/12/91	29		82	12.4
09/12/91	164	119.2	113	
09/12/91	460	134.9 *	89	12.9
10/18/91	56	131.5	151	
10/18/91	56	132.1	160	
11/05/91	38	129.2	102	
11/05/91	38	131.4	97	
11/05/91	38	127.2	125	
11/05/91	38	129.5	91	
11/05/91	38	130.1	94	
11/05/91	38	129.8	89	
11/05/91	406	137.6 *	107	10.4
02/28/92	28	133.7	57	12.8
02/28/92	28	135.0	56	13.0
02/28/92	56	135.7	99	13.1
02/28/92	56	134.6	98	13.1
02/28/92	203	133.8	190	

DATE CAST	AGE AT TEST (DAYS)	UNIT WEIGHT (lbs/ft^2)	COMPRESSIVE STRENGTH (psi)	MOISTURE CONTENT (%)
02/28/92	291	134.3	135	13.5
02/28/92	291	133.3	168	12.8
03/16/92	28	132.4	36	14.5
03/16/92	28	131.7	41	14.0
03/16/92	56	133.1	62	13.0
03/16/92	56	132.9	82	13.6
03/16/92	186	132.0	151	
03/16/92	274	131.4	144	14.2
03/16/92	274	133.3	129	13.6
03/17/92	28	126.3	57	12.2
03/17/92	28	130.5	70	14.2
03/17/92	57	132.7	118	13.9
03/17/92	57	132.0	88	14.4
03/17/92	185	133.0	128	
03/17/92	273	130.6	130	15.6
04/06/92	35	136.0	242	13.6
04/06/92	35	134.9	218	13.8
04/06/92	58	135.9	328	
04/06/92	58	134.8	306	
04/06/92	165	137.8	758	
04/06/92	253	136.5	955	13.7
05/06/92	28 **	140.2	189	12.3
05/06/92	28 **	138.8	179	12.5

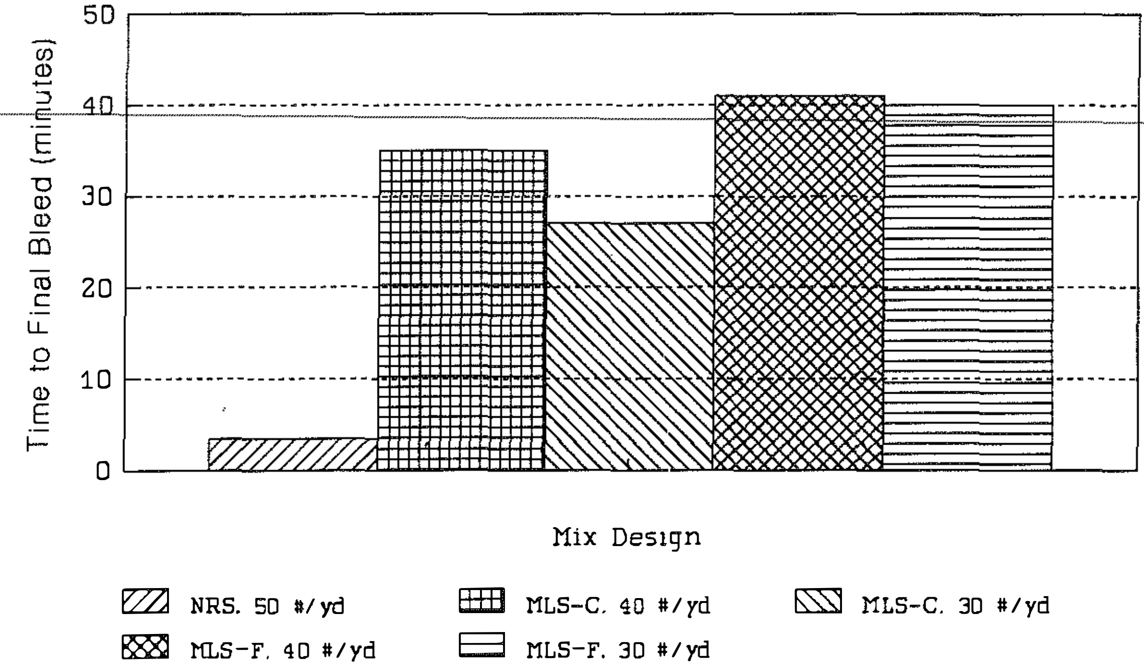
Note: * indicates samples were allowed to dry then were rewet
** indicates samples made using manufactured limestone sand

APPENDIX F

GRAPHS AND TABLE OF DATA FROM MIX DESIGN STUDY

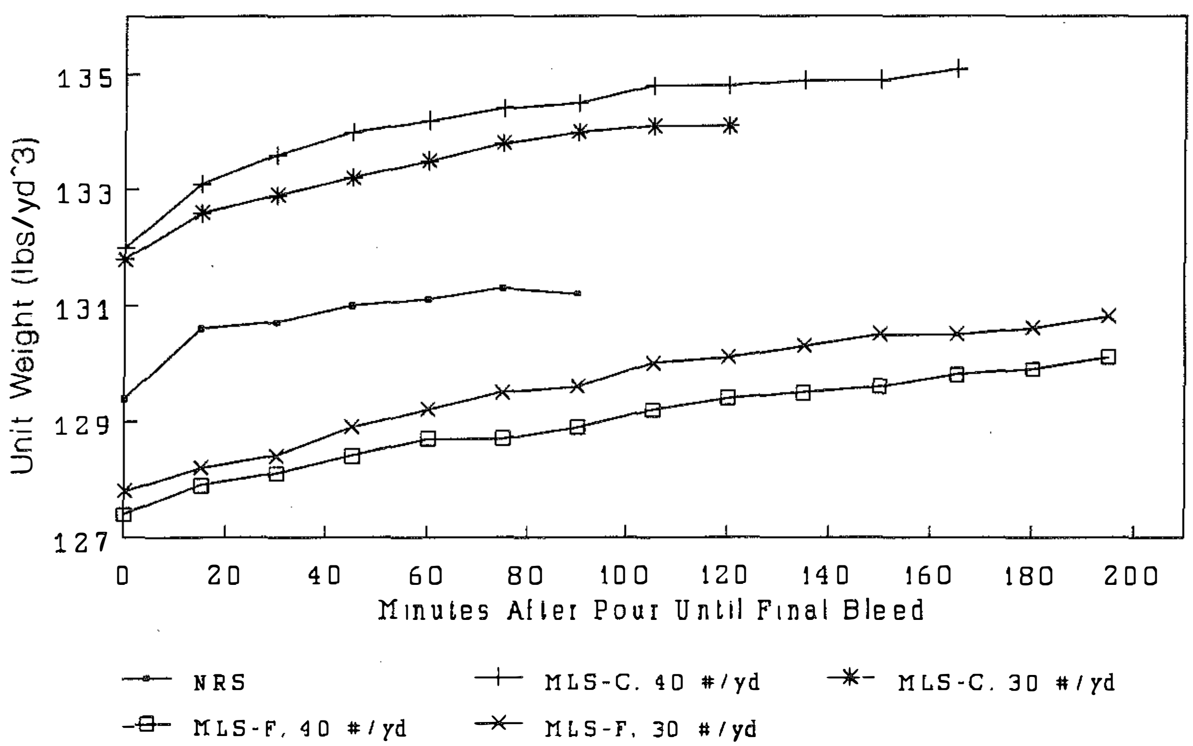
Unit Weights, Compressive Strengths, and Cured Moisture Contents of Laboratory CLSM Mixtures

Aggregate Grading	NRS	MLS Coarse	MLS Coarse	MLS Fine	MLS Fine
Cement Content (lb/yd^3)	50	40	30	40	30
Wet Unit Weight (lb/ft^3)	129.4	132.1	131.8	127.4	127.8
Unit Weight at Final Bleed (lb/ft^3)	131.3	135.1	134.1	130.0	130.9
Unit Weight Four Hours After Final Bleed (lb/yd^3)	131.5	135.2	134.5	130.5	131.3
Cured Unit Weight (lb/ft^3)	131.4	135.7	134.5	130.4	131.1
Compressive Strength (psi)	22.5	46.2	27.5	39.8	30.2
Cured Moisture Content (%)	14.8	13.9	14.2	18.0	17.7

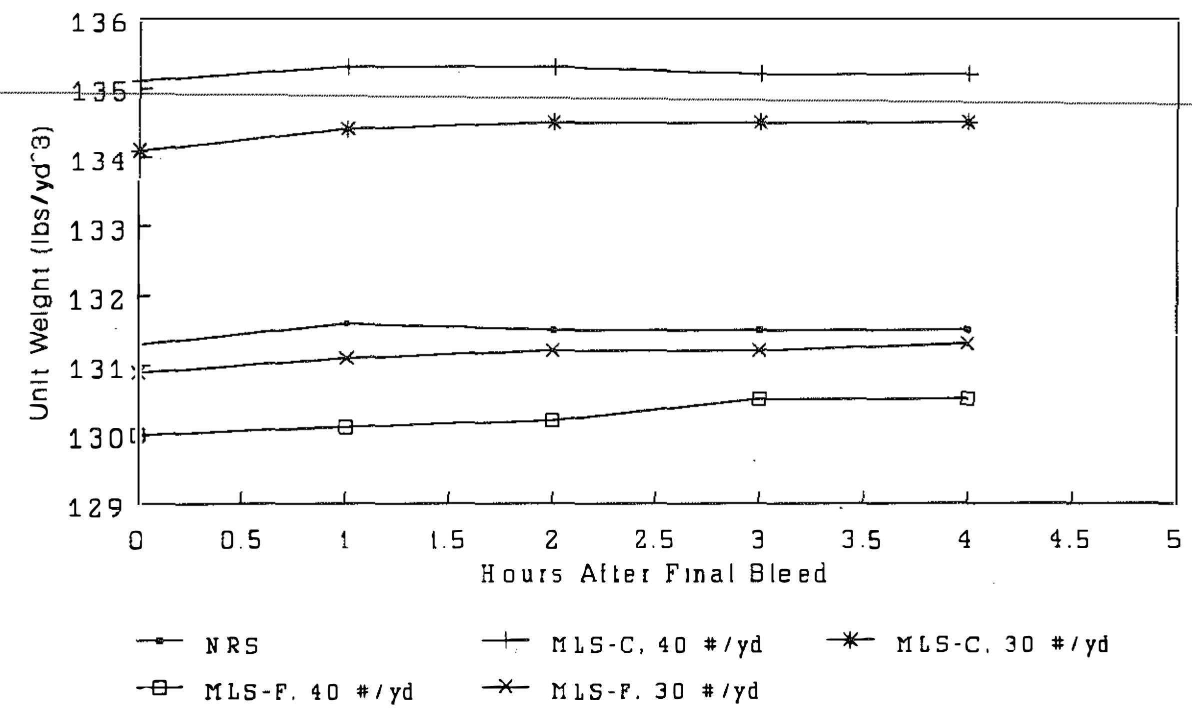


Mix design varies type sand, gradation, and cement content.

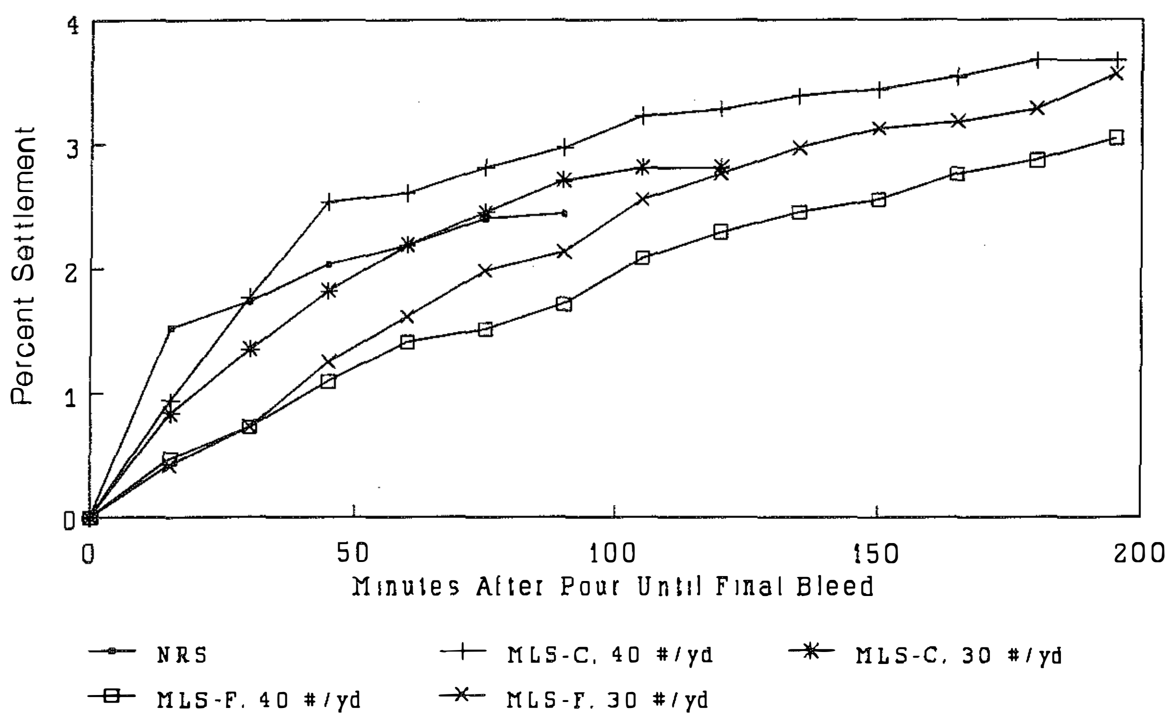
Time to final bleed as a function of the CLSM mixture designs.



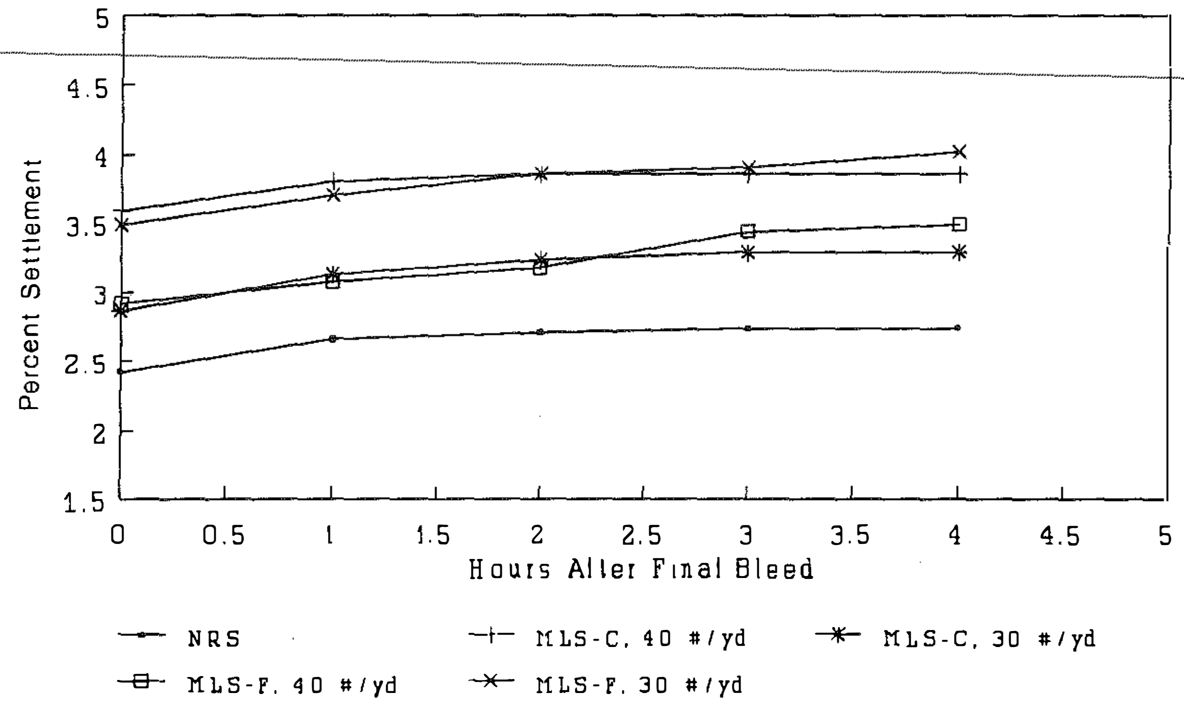
Unit weight of the CLSM mixtures as a function of time until final bleed.



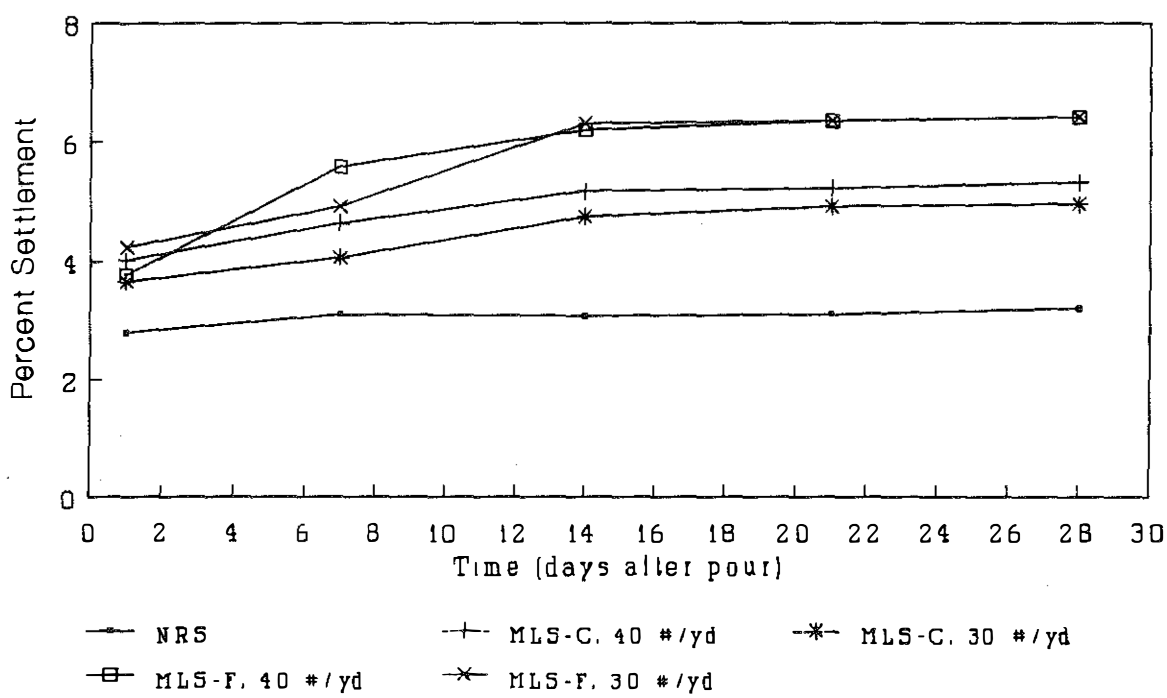
Unit weight of the CLSM mixtures as a function of the time after final bleed.



Percent settlement of the CLSM mixtures as a function of the time until final bleed.



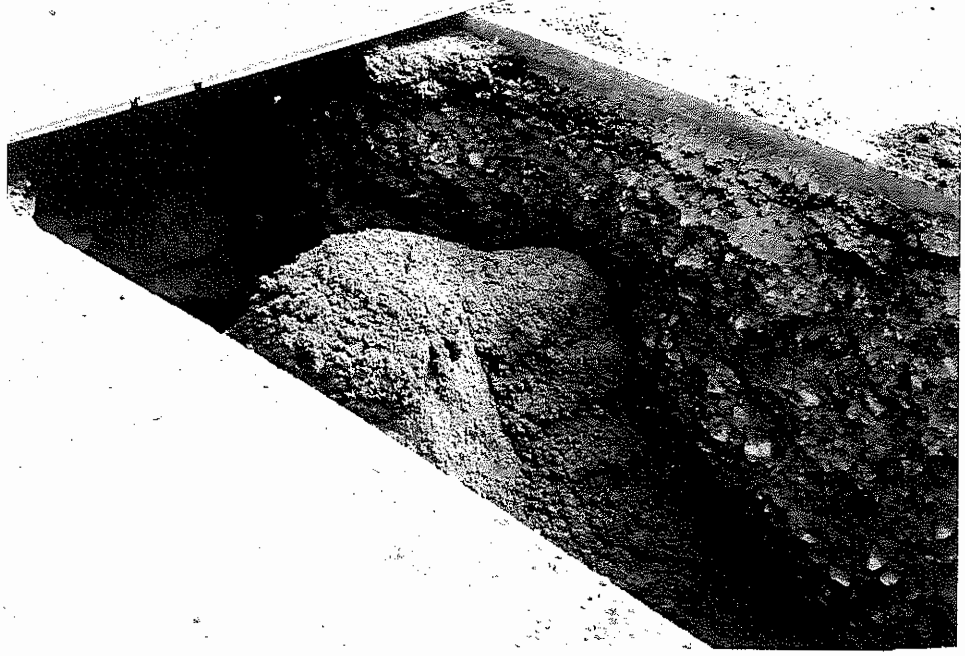
Percent settlement of the CLSM mixtures as a function of the time after final bleed.



Percent settlement of the CLSM mixtures as a function of time after pour.

Figure 3. *Illustrative of CLSM placed at Site 2. Material is dry enough to stack and should not be used as trench backfill.*

Figure 4. *Representative of CLSM used at Site 2. Water has been added to original mix. CLSM exhibiting cracks is not satisfactorily flowable.*



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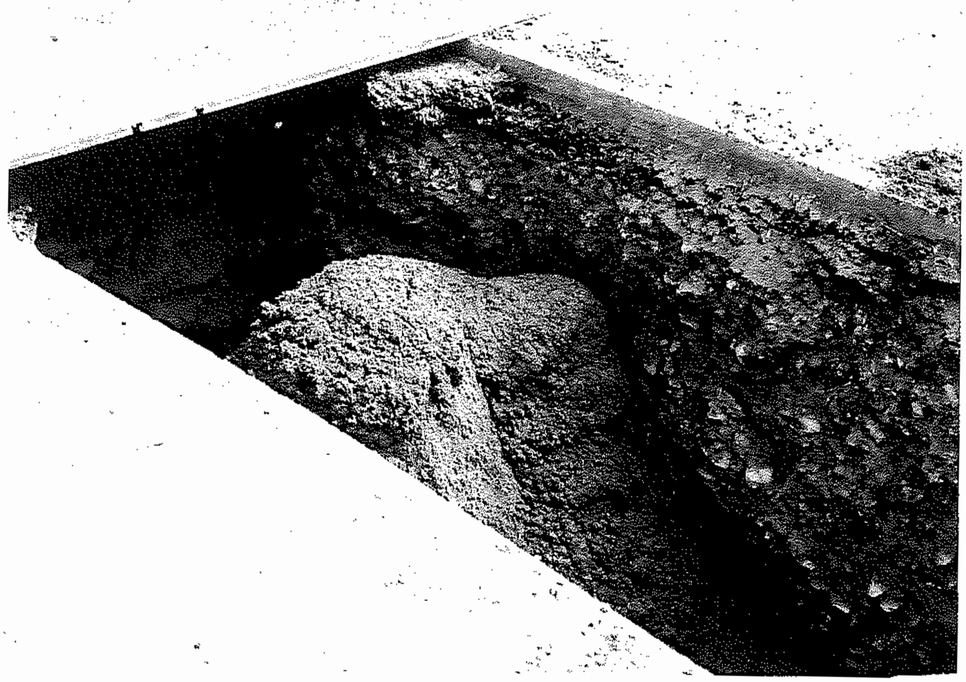

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Figure 5. *Voids under pipe where dry CLSM was used as backfill.*

In order to receive shipment of the meters in time for the first installation, the meters were ordered before a thorough analysis of the instrumentation needs were completed. Six meters were obtained for installation at Site 1 and later, four were obtained for Site 2. A finite element analysis (1) indicated that the culverts placed in a cradle and backfilled with CLSM could have high loading at the interface of the bedding and CLSM.

At Site 1, two culverts had a meter installed on top and underneath each pipe. The meters were placed under the driving lanes. These pipes were at Stations 94+44, 24 inch, and 97+60, 18-inch equivalent. One 36-inch culvert at Station 112+37 received one meter underneath the pipe and one in the bedding immediately below the CLSM. The three instrumented pipes were backfilled with CLSM right of centerline and with conventional backfill left of centerline. Typical sections showing both instrumentation schemes are shown in Figures 6 and 7. Two meters were installed, top and bottom, on the conventional backfill end of the pipe at station 97+60.

Four meters were installed at Site 2. Two culverts were instrumented with a meter placed on top of each culvert and a meter placed underneath each culvert. For reasons

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Figure 18. *CLSM at Site 1 after adjusting the mix. Material was flowable and workers with shovels were not used after first day.*

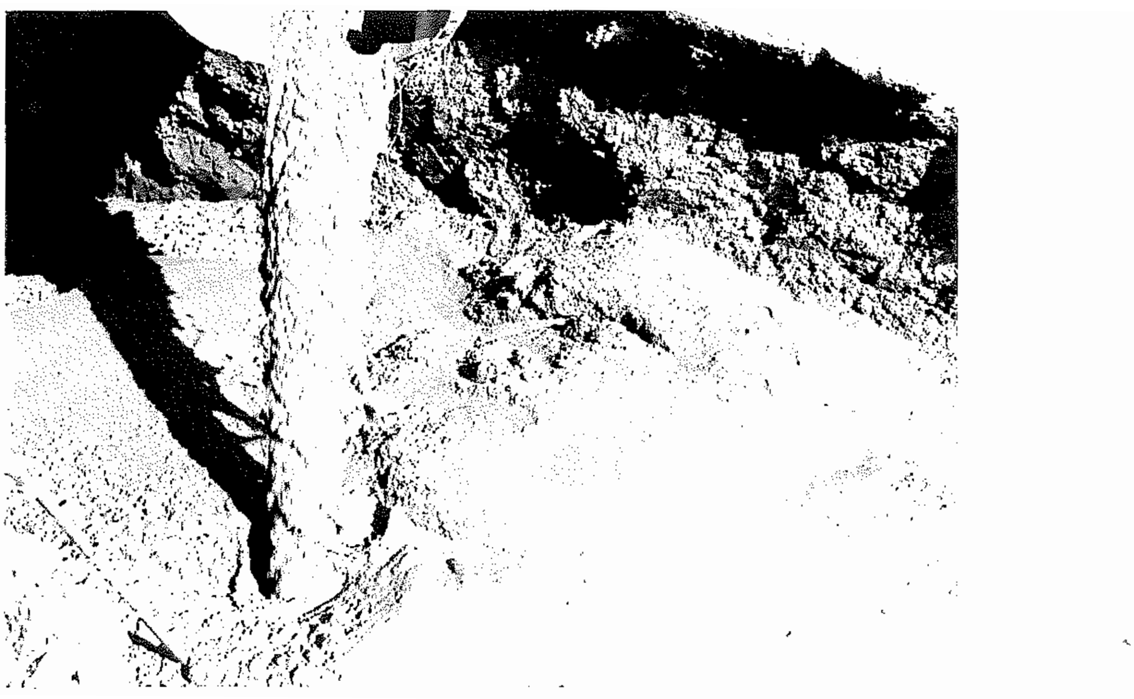
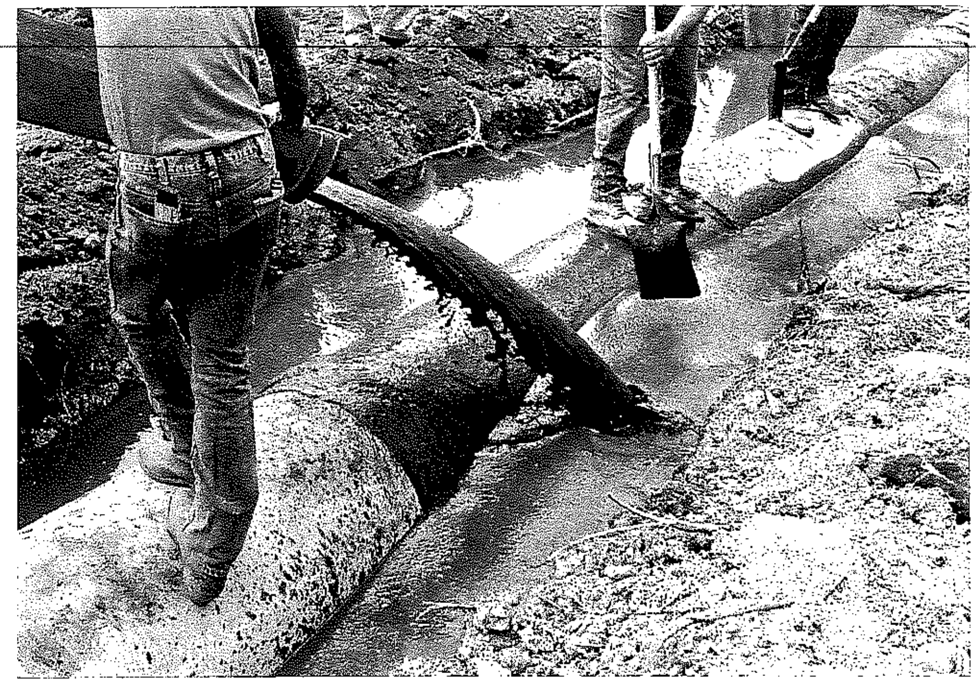


Figure 19. *CLSM at Site 1 with visible channels from bleed water runoff and fine material washed to the surface by bleeding.*



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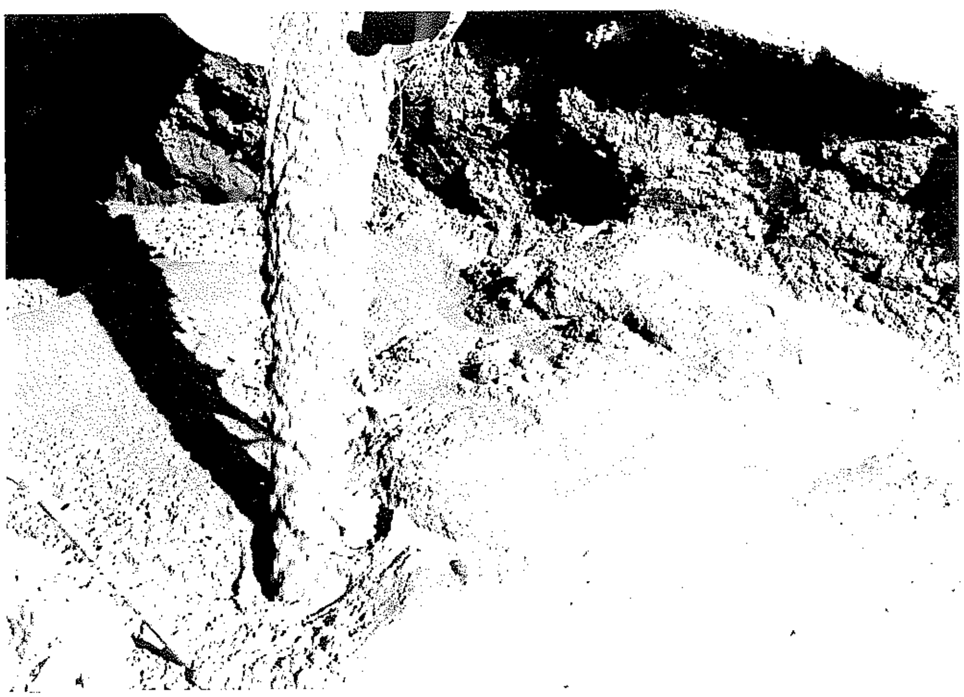

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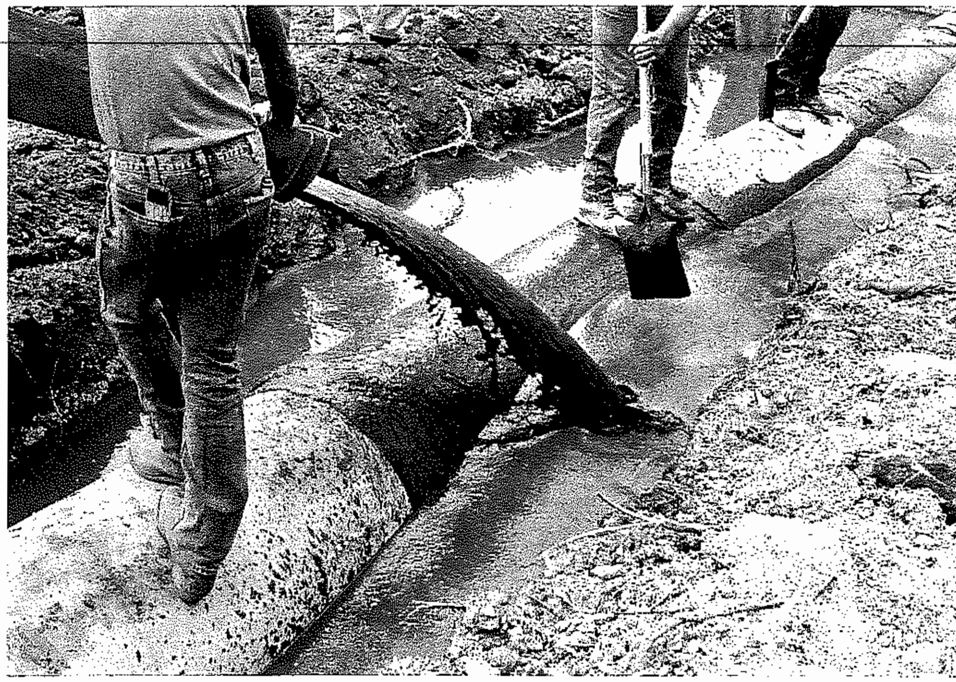

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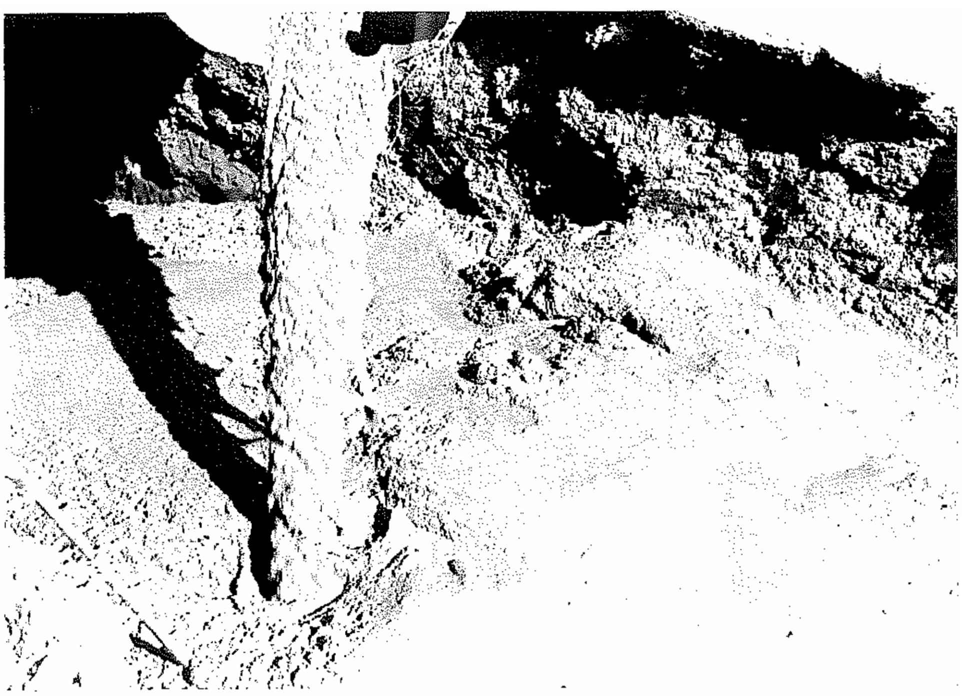

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